VOLUME LXIV NUMBER 4

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

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NOVEMBER 1926

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS, U.S.A.

THE CAMBRIDGE UNIVERSITY PRESS, LONDON
THE MARUZEN-KABUSHIKI-KAISHA, TOKYO, OSAKA, KYOTO, FUKUOKA, SENDAI
THE COMMERCIAL PRESS, LIMITED, SHANGHAI

November 1926 Vol. LXIV, No. 4

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The Astrophysical Journal is published by the University of Chicago at the University of Chicago Press, 5750 Ellis Avenue, Chicago, Illinois, during each month except February and August. ¶ The subscription price is $6.00 a year; the price of single copies is 75 cents. Orders for service of less than a half-year will be charged at the single-copy rate. ¶ Postage is prepaid by the publishers on all orders from the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Dominican Republic, El Salvador, Argentina, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua, Peru, Uruguay, Paraguay, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands, and Spain. ¶ Postage is charged extra as follows: for Canada and Newfoundland, 30 cents on annual subscriptions (total $6.30); on single copies, 3 cents (total 78 cents); for all other countries in the Postal Union, 50 cents on annual subscriptions (total $6.50), on single copies 5 cents (total 80 cents). ¶ Patrons are requested to make all remittances payable to The University of Chicago Press in postal or express money orders or bank drafts.

The following are authorized to quote the prices indicated:

For the British Empire: The Cambridge University Press, Fetter Lane, London, E.C. 4. Yearly subscriptions, including postage, £1 12*s*. 6*d*. each; single copies, including postage, 4*s* each.

For China: The Commercial Press, Ltd., Paoshon Road, Shanghai. Yearly subscriptions, $6.00; single copies, 75 cents, or their equivalents in Chinese money. Postage extra, on yearly subscriptions 50 cents, on single copies 5 cents.

Claims for missing numbers should be made within the month following the regular month of publication. The publishers expect to supply missing numbers free only when losses have been sustained in transit, and when the reserve stock will permit.

Business Correspondence should be addressed to The University of Chicago Press, Chicago, Illinois.

Communications for the editors and manuscripts should be addressed to the Editors of THE ASTROPHYSICAL JOURNAL, Yerkes Observatory, Williams Bay, Wisconsin.

The cable address is "University, Chicago."

The articles in this Journal are indexed in the *International Index to Periodicals*, New York, N.Y.

Entered as second-class matter, January 17, 1895, at the Post-office at Chicago, Ill., under the Act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October, 3, 1917, authorized on July 15, 1918

PRINTED IN THE U.S.A.

ALFRED PEROT
1863–1925

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VOLUME LXIV NOVEMBER 1926 NUMBER 4

ALFRED PEROT

By CHARLES FABRY

The narrowing of the gap between physics and astronomy is perhaps the most striking fact in the modern development of astronomy. The two sciences are today closely linked; every discovery in physics raises the hope of an astronomical application, and, conversely, many important problems have been set for the physicist by observations of an astrophysical character. Physics thus now occupies the position in respect to astronomy which was held by pure mathematics at the time of Laplace.

This interrelation between physics and astronomy has characterized the scientific career of the late Alfred Perot.

Born at Nancy in 1863, Perot made good progress in the secondary schools of his native city. In 1882, he entered the École Polytechnique at Paris, where the instruction is largely based on mathematics. Completing his course there in 1884, he returned to Nancy where he began work almost immediately in the physical laboratory of the university, under the direction of Blondlot. In 1888 he received the Doctor's degree, his thesis being entitled "Sur la mesure des volumes spécifiques des vapeurs saturantes, et mesure de l'équivalent mécanique de la chaleur." This research has remained a classic in France, as it well deserves to be, on account of the simplicity, precision, and elegance of the methods. In the same saturated vapor, Perot measured all the thermodynamic constants; and was thus able, by means of the equation of Clapeyron, to calcu-

late the mechanical equivalent of the calorie. The excellent agreement between his result and the best direct measures by Joule and by Rowland constitutes a good confirmation of the principles of thermodynamics.

Upon receiving his degree, Perot was appointed Maître de Conférences at the University of Marseille. He then devoted himself chiefly to electricity, and published some researches on the Hertzian waves which had just been discovered, and on the properties of dielectrics. The electrical industry was then in a stage of rapid development, which Perot followed with careful attention, and he thus became an expert who was often consulted in questions of industrial electricity.

He became professor of industrial electricity at the University of Marseille in 1894, and I then succeeded him as Maître de Conférences. Our collaboration, which continued through many years, began at this time.

The subject on which we began to work together had occurred to me, partly by chance, following an observation in an electrical problem. A young physicist who was working with me wished to study the spark discharges passing between metallic surfaces separated by the very small space of a micron or less; he consulted me as to the method which he could employ to measure such small distances. I was already familiar with the phenomena of interference; and I thought at once that the interference methods would be the only ones capable of giving the required precision. The idea came to me that it would be easy to solve the problem if it were possible to observe the interferences produced, across the metal, and I thought that would be possible by using a lightly silvered glass plate. A trial at once showed that this could be done; I was immediately struck by the singular appearance of the fringes, which were visible as very fine lines, and showed, toward the five hundredth fringe, the doubling of the sodium line instead of the disappearance which was ordinarily observed. I had already met with similar conditions in fringes observed in the neighborhood of total reflection (Herschel's fringes); the high reflecting power of the silvered surface was evidently the cause of the phenomenon.

I immediately commenced with Perot the study of fringes of

silvered films, and numerous applications followed. The first was the construction of an absolute electrometer, in itself of no great importance, but it gave us a chance to develop rapid methods of measuring thickness by interference, by means of superposed fringes. Perot, who was very skilful mechanically, had the principal part in the construction of our electrometer, while I attended especially to the optical part.

Being well experienced in dealing with fringes from silvered films, we at once began to develop their application to optics and metrology. It was possible to make rapid measures of the lengths of gauges used in precise mechanical work, and at the same time to study the structure of the fine spectral lines discovered by Michelson. At this time Macé de Lépinay was carrying on in the laboratory at Marseille another series of researches on optical metrology, especially on the determinations of the mass of a cubic decimeter of water. It is well known that the founders of the decimal metric system had chosen the unit of mass in such a way that a cubic decimeter of water should be as nearly as possible 1 kg; but it was difficult to say with what precision this intention had been realized with the imperfect means available at the end of the eighteenth century. During the whole century following, attempts had been made to solve the question; contradictory results had been obtained, some of which, had they been exact, would have led to the conclusion that the founders of the metric system had attained only a very moderate precision. We know today, as a result of the researches of the International Bureau of Weights and Measures, that such a conclusion would have been entirely erroneous; the determinations in 1795 were much more precise than those made almost a century later. This was an entirely open question when Macé de Lépinay began to measure lengths by interference methods. Long before this, Fizeau had introduced the interference method for measuring small displacements, such as those met with in the study of expansion; but light-waves had never before been used to measure the dimensions of a solid body. Thus Macé de Lépinay was the first, in 1885, to attempt to solve this problem; he showed that the thickness of a transparent film could be expressed in wave-lengths by the use of Talbot's bands. Later, after Michelson had established the relation-

ship between a wave-length and the meter, Macé de Lépinay undertook to determine the dimensions of a cube of quartz in order to deduce the specific mass of water by measuring the upward pressure which the cube sustained in the water. Unfortunately, the method of Macé de Lépinay required a knowledge of the index of refraction of quartz, which is difficult to obtain to the high degree of precision required.

This was a good chance for Perot and myself to apply our methods; with Macé de Lépinay we were able to measure in the course of a few days the dimensions of the cube of quartz, which led to the first, and almost exact, value of the mass of a cubic decimeter of water.

Although metrologists had universally adopted Michelson's value for the wave-length of the red line of cadmium, spectroscopists continued to employ the wave-lengths given in the splendid work of Rowland. It was well known, however, that there was a discrepancy of about 1/30,000 between Michelson's values and those of Rowland, due to an error made in determining the basic absolute wave-length of the sodium line by means of a grating. It seemed to me that it would be useful to determine the exact ratio between Rowland's unit and the correct metric value resulting from Michelson's measures. Since Rowland had studied especially the solar lines, and the emission spectra of metals only in an incidental way, it seemed necessary to settle the question by a direct comparison between the cadmium line emitted by Michelson's tube and some lines of the solar spectrum. In 1899, with the help of Perot, I attempted a comparison by direct visual observations in a spectrum produced by a large concave grating; the result was a complete checkmate; it was impossible to obtain a consistent series of results. It became evident to us that the problem could only be settled by using interference methods; but the difficulty was to obtain interferences with dark lines of the solar spectrum. This was accomplished quickly enough by bringing into the silver-film interferometer a small part of the solar spectrum containing a dark line; dark rings corresponding to this dark line were obtained. The principle having been found, the task in hand was indeed long; in the rooms available at the

laboratory at Marseille the sun shone only for a very short time, and the conditions of stability in the building were only moderately good. The opportunity was offered to us to do our work at the Observatory, by its director, our friend E. Stéphan. However, gas and electricity (storage batteries excepted) were not available there, and it was not until July, 1901, that these difficulties were overcome. The result was the discovery of small systematic errors in Rowland's tables. Later, with the collaboration of M. Buisson, we established the series of spectral lines forming what has become the international system of wave-lengths.

In 1901, the French government having decided upon the creation of the Laboratoire d'Essais in Paris, Perot was called to organize and direct it. This laid upon him for a number of years a difficult and absorbing administrative task. However, he did not give up his personal researches; several pieces of work date from this time, such as the resistance of materials, measurements of pressures, and also the new determination of the meter in wave-lengths made in his laboratory with Benoît and myself, which completely confirms Michelson's result.

In 1908, Perot gave up the direction of the Laboratoire d'Essais in order to devote himself anew to pure science and to teaching. He became professor in the École Polytechnique (where he succeeded Henri Becquerel), and physicist at the Observatory of Meudon.

Perot occupied himself especially with solar physics, in applying the interference method to the measurement of small displacements of spectral lines. He was thus able to obtain interesting results on vertical movements in the solar atmosphere, and attempted to apply the same method to absorbing centers in the terrestrial atmosphere by the study of the telluric lines. To him we owe the determination of the pressure of the reversing layer, indicating that this pressure is feeble and cannot explain the discrepancy between the solar and the arc lines.

During the war, Perot was engaged, with his friend General Ferrié, in problems relating to communication, which led him to a profound knowledge of the marvelous lamp having three electrodes. He made a series of ingenious applications of this, including among

other things an apparatus for measuring the terrestrial magnetic field; the definitive model of this was under construction at the time of his death.

An operation, which he underwent two years before, had affected his health without in any way diminishing his activity. He died November 28, 1925, aged only sixty-two years.

Perot was personally not widely known abroad, as he had traveled but little, not willingly leaving his family. He married at an early age, and is survived by five children and many grandchildren. Only those who knew him intimately could appreciate the vivacity and breadth of his spirit. He was especially skilful in realizing his ideas; he liked to gather good workmen about him for the construction of his apparatus, but he was always the most skilful of those in the workshop. His death was a heavy loss to science and leaves a great void among those who knew him.

Laboratoire de Physique
Université de Paris
November 24, 1926

TWO NEW VARIABLE STARS OF THE TYPE OF W URSAE MAJORIS[1]

By J. SCHILT

ABSTRACT

Two new variables like W Ursae Majoris.—The variability of 44*i* Boötis (fainter component) = Boss 3846 = Σ 1909 (ft.), and of B.D. +75°752 = Cin. 4000, have been investigated on account of *peculiarities in their spectra.* The variability of both stars is demonstrated. The periods of revolution (i.e., the double light-period) are of the order of $0^{d}.3$, and the light-curves very much resemble that of W Ursae Majoris. The range of magnitude is about 0.7 for 44*i* Boötis and 0.35 for B.D. +75°752. 44*i* Boötis is of special interest because it is a *component* of a *visual binary* of well-marked orbital motion and of large parallax. Both stars have large proper motions.

44*i* BOÖTIS (FAINTER COMPONENT)

$15^{h}\ 0^{m}\ 29^{s}, +48^{\circ}\ 2'\ 34''$ (1900), Harvard Visual Magnitude 6.1

This star is the fainter component of the well-known binary Σ 1909. The two components show a well-marked binary motion. The companion reached apastron about 1870 at a distance of 5″ from the brighter star. Since then the distance has decreased with an accelerating rate and amounts at present to about 3″, so that it is still just possible to get separate images with a long-focus instrument for the purpose of photographic photometry. Measurements by Hertzsprung[2] of four plates taken in the years 1915–1916 show differences which at the time were not regarded as real. The present observations were suggested by the resemblance of the spectrum to that of W Ursae Majoris.[3] The 60-inch telescope has been used with the Cassegrain (80 ft.) focus, for which the distance between the components on the plates is 0.36 mm. The plates used were Eastman 33.

About one hundred exposures of 5 and 10 seconds, alternately, were usually made on each plate. The total number of plates is thirty. The images have been measured with a thermopile photome-

[1] *Contributions from the Mount Wilson Observatory*, No. 316.

[2] *Publikationen des Astrophysikalischen Observatoriums zu Potsdam*, **24**, Stück 2, 32, 1920.

[3] Adams, Joy, Strömberg, and Burwell, *Mt. Wilson Contr.*, No. 199; *Astrophysical Journal*, **53**, 94, 1921. Estimated spectrum G2p; measured, G4. Lines described as very poor, resembling those of W Ursae Majoris.

TABLE I

OBSERVATIONS OF 44*i* BOÖTIS

Plate No.	Astronomical Date	No. Images Measured	J.D. Hel. G.M.T.	Epoch and Phase*	Δm	Quality†
	1926		2424000+			
SS 161......	April 18	23	642.7996	0.013	0.61	p
SS 162......	April 18	16	.8948	.369	1.03	f
		23	.8981	.381	1.00	
SS 163......	April 18	14	.9310	.437	0.80	f
		13	.9152	.445	.75	
		22	.9179	.455	.76	
SS 164......	April 18	21	.9410	.541	.55	p
		33	.9452	.557	.60	
SS 168......	April 19	22	625.7158	3.435	.95	p
		13	.7190	.447	.87	
SS 169......	April 19	20	.8916	4.091	.80	p
		21	.8946	.102	.80	
		21	.8977	.114	.75	
		18	.9009	.126	.70	
SS 192......	May 7	25	643.7495	70.784	.95	f
		22	.7532	.798	0.99	
		24	.7572	.812	1.04	
		22	.7608	.826	1.15	
SS 193......	May 10	24	646.6754	81.711	0.85	f
		14	.6796	.726	.84	
		20	.6827	.738	0.97	
SS 194......	May 10	24	.6988	.798	1.18	f
		26	.7034	.815	1.28	
		28	.7075	.831	1.38	
		18	.7113	.845	1.15	
		25	.7141	.855	1.15	
SS 195......	May 10	22	.7258	.899	1.07	f
		30	.7293	.912	0.98	
		25	.7376	.943	.87	
		24	.7411	.956	.86	
SS 196......	May 10	27	.7584	82.021	.75	f
		34	.7625	.036	.73	
		29	.7674	.054	.72	
		26	.7736	.078	.71	
SS 197......	May 10	27	.7930	.150	.85	p–f
		30	.8006	.178	.90	
		32	.8068	.202	.96	
		28	.8131	.225	0.98	
SS 198......	May 10	30	.8311	.292	1.19	g
		26	.8608	.403	0.98	
		27	.8663	.424	.82	
		27	.8705	.439	.88	
SS 199......	May 10	25	.8864	.499	.78	g
		27	.8906	.514	.72	
		23	.8955	.533	.69	
SS 200......	May 10	28	.9101	.587	.75	f
		30	.9156	.608	.75	
		24	.9239	.639	.86	
		24	.9288	.657	0.80	

* Phase is expressed as a fraction of the period.

† p = poor; f = fair; g = good.

TABLE I—*Continued*

Plate No.	Astronomical Date	No. Images Measured	J.D. Hel. G.M.T.	Epoch and Phase*	Δm	Quality†
	1926		2424000+			
SS 201......	May 10	32	646.9455	82.720	1.00	f
		27	.9517	.743	0.99	
		29	.9579	.766	1.07	
		31	.9627	.784	1.34	
SS 202......	May 10	26	.9800	.848	1.19	p
		21	.9869	.874	1.06	
		26	.9911	.890	1.04	
		22	.9952	.905	0.96	
SS 240......	June 11	28	678.6665	201.185	.80	f
		26	.6702	.199	.81	
		25	.6737	.212	.87	
SS 241......	June 11	24	.7662	.558	.77	f
		20	.7709	.575	.71	
		18	.7756	.593	.82	
		27	.7795	.607	.75	
SS 242......	June 11	25	.7954	.667	.75	f
		29	.8032	.696	.87	
		30	.8078	.713	.87	
		26	.8120	.729	0.87	
SS 243......	June 11	30	.8271	.785	1.10	f–p
		24	.8334	.809	1.19	
		24	.8376	.824	1.25	
		24	.8411	.837	1.37	
SS 244......	June 11	21	.8684	.939	0.84	f–p
		28	.8752	.965	.89	
		24	.8829	.994	.85	
		26	.8862	202.006	.83	
SS 245......	June 11	25	.8993	.055	.80	f
		25	.9055	.078	.80	
		25	.9103	.096	.77	
		22	.9136	.108	.76	
SS 246......	June 11	29	.9279	.162	.78	p–f
		24	.9318	.176	.80	
		25	.9374	.197	.84	
		23	.9428	.217	.87	
SS 247......	June 11	23	.9555	.265	0.98	p–f
		24	.9590	.278	1.02	
		21	.9621	.289	1.10	
		10	.9642	.297	1.09	
SS 293......	July 9	23	706.6682	305.761	1.05	f–p
		25	.6725	.777	1.04	
		20	.6756	.788	1.19	
		23	.6786	.800	1.17	
SS 294......	July 9	15	.6843	.821	1.40	f
		21	.6868	.830	1.25	
		15	.6892	.839	1.35	
SS 295......	July 9	21	.7799	306.178	0.75	g
		26	.7836	.192	.80	
		24	.7884	.210	.85	
		24	.7932	.228	0.85	

* Phase is expressed as a fraction of the period.

† p=poor; f=fair; g=good.

TABLE I—*Continued*

Plate No.	Astronomical Date	No. Images Measured	J.D. Hel. G.M.T.	Epoch and Phase*	Δm	Quality†
	1926		2424000+			
SS 296......	July 9	26	706.8121	306.298	1.08	f
		22	.8160	.313	1.07	
		24	.8203	.329	1.17	
		23	.8237	.342	1.14	
SS 297......	July 9	24	.8321	.373	1.18	g
		29	.8380	.395	1.13	
		25	.8426	.412	1.10	
		24	.8467	.428	1.05	
SS 298......	July 9	18	.8547	.457	0.92	g
		18	.8575	.468	.94	
		22	.8605	.479	.92	
		23	.8640	.492	0.87	

* Phase is expressed as a fraction of the period.
† p = poor; f = fair; g = good.

ter, an occasional image being rejected because of poor quality. The readings for successive exposures of the same duration were combined into means of from two to five groups for each plate. The difference in brightness of the two components of the binary was then computed for each group from

$$\Delta m = \frac{(f_{10}+f_5)-(b_{10}+b_5)}{(f_{10}-f_5)+(b_{10}-b_5)} \times 0.75 \ ,$$

where b_5, b_{10}, f_5, and f_{10} are the mean readings for the 5- and 10-second exposures on the bright and faint images, respectively, and where it is assumed that the difference between the images of a 5- and 10-second exposure is equivalent to 0.75 mag. The results are given in Table I. The corresponding epochs of observation are in J.D. Heliocentric G.M.T., and refer to the mean of the beginning of the first and the end of the last exposure of each group.

The period of revolution, derived by least squares, is 0.267765 ± 0.000012 day. The corresponding epoch numbers and phases given in Table I have been counted from an arbitrary zero. The phases are expressed in fractions of the period. The individual observations are plotted in Figure 1. Combining them into groups of five in order of phase, we obtain the normal points given in Table II. These are indicated by the crosses in Figure 1 which are connected by the broken line.

The figure shows a number of discordant observations. An attempt has been made to connect these with the quality of the plates, but with only partial success. It is to be expected that the measured difference Δm between the rather close components will depend on the seeing. The seeing was often rather bad and, in consequence, the images are frequently large and even tend to overlap. In these cases the measured Δm is probably too small, since a setting on the larger star does not include the whole image, while one on the smaller

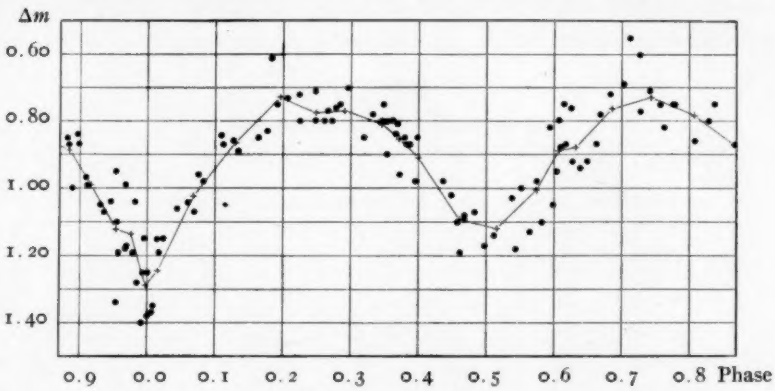


FIG. 1.—44*i* Boötis

star may include a portion of the image of the larger star; further, the Eberhard effect may also enter as a possible source of disturbance. In fact, the three measures giving Δm less than 0.68 are all from poor plates.

Considering the difficulty of the object and the poor conditions under which part of the plates have been taken, the light-curve is satisfactory, and reveals at once a variation of the type of W Ursae Majoris. Without laying too much stress on the observed inequality in the depth of the minima, the one to the left in the figure may be considered as the primary. The primary minimum has been determined to be at phase 0.832P, the secondary at 0.332P. The resulting elements are

$$\text{Min. Hel. J.D. G.M.T.} = 2424646.976 + 0.267765\,E.$$
$$\pm 0.002 \pm 0.000012 \text{ (m.e.)}$$

Δm at maximum is 0.76; at primary minimum, 1.29; at secondary minimum, 1.12.

Remarks.—1. A spectrogram obtained on May 28, 1926, with the 18-inch camera at the 60-inch telescope during predicted time of maximum light gives good indication of double lines, which, however, are wide and diffuse. The separation corresponds to about 350 km/sec. Spectrograms taken during minimum on July 17 and 18 by Mr. Joy with the 10-inch camera at the 100-inch reflector, and by the writer with the 7-inch camera at the 60-inch, show the lines to be distinctly narrower at the time of eclipse. Mr. Joy states: "The lines are quite measurable during minimum. They diminish in width during the half-hour preceding minimum."

TABLE II

NORMAL POINTS FOR 44*i* BOÖTIS

Phase	Δm	Phase	Δm	Phase	Δm
0.015	1.24	0.399	0.91	0.806	0.78
.066	1.02	.461	1.10	.883	0.89
.129	0.86	.515	1.12	.917	0.99
.196	0.73	.573	1.01	.954	1.12
.248	0.78	.607	0.89	.976	1.14
.290	0.77	.631	0.88	0.996	1.29
.346	0.81	.686	0.76		
0.370	0.85	0.744	0.73		

2. The proper motion for the center of gravity of the visual pair, assuming equal masses, is 0."407. The trigonometric parallax is 0."076, the mean of the Allegheny and Yerkes determinations. The star is evidently a dwarf; the spectroscopic absolute magnitude is +5.2;[1] and its apparent magnitude, 6.1, is the brightest known for this class of variation.

3. As a consequence of the motion in the visual orbit, the apparent period of the variable in all probability cannot be constant. The projected distance between the visual components at present is about 40 astronomical units, and a rough calculation shows that the change in period should be perceptible as soon as uniform observations cover a period of about ten years.

4. The observed amplitude corresponds to a range of 0.1 mag. in the total light of the visual pair, which is perfectly within the reach of the photo-electric cell. This perhaps affords the only meth-

[1] *Mt. Wilson Contr.*, No. 199, p. 57; *Astrophysical Journal*, **53**, 69, 1921.

od by which the variation can be followed when the distance between the components becomes very small.

5. From the range in radial velocity, provisionally adopted as 350 km/sec., the distance of the components is 1.33 million km; and the masses, assumed equal, are $m_1 = m_2 = 0.64\,\odot$. A rough calculation gives for the average radius of the ellipsoidal bodies 0.43 million km, and a density 2.2 times that of the sun. Since the absolute magnitude for each component is 6.25, the surface brightness is +0.38 mag. ($\odot = 0$). The value given by Seares for dwarfs of estimated spectrum G2 is +0.10 mag.[1] The effective temperature T

TABLE III

COMPARISON STARS FOR B.D.+75°752

STAR	B.D. No.	*Draper Catalogue*		ADOPTED PG. MAG.
		Pg.	Spectrum	
a............	+75°765	7.93	K2	8.00
b............	74 890	7.47	A3	7.36
c............	74 889	8.7	G5	8.52
d............	76 809	7.41	F2	7.48
e............	+74 877	8.6	A2	8.83

by Hertzsprung's[2] formula is 5500°. The star falls almost exactly on Eddington's curve, giving the relation between mass and absolute magnitude. The ratio of the distance between the eclipsing components to the projected distance on the sphere between the visual components is 1:4500.

B.D.+75°752 = CIN. 4000

$20^h\ 38^m\ 42^s$, +75° 13′ 51″ (1900) Harvard Visual Magnitude 8.4, Sp. G5

The spectrum of this star has also been classified as resembling that of W Ursae Majoris by Mr. Adams, who kindly drew my attention to it.

One hundred and six plates have been obtained with the 10-inch Cooke refractor of 45-inch focal length. With the exception of the first two, which were test plates, they were all secured

[1] *Mt. Wilson Contr.*, No. 226, p. 34; *Astrophysical Journal*, **55**, 198, 1922.

[2] *Zeitschrift für Wissenschaftliche Photographie*, **4**, 43, 1906.

TABLE IV

Observations of B.D. $+75^{\circ}752$

Plate No.	Astron. Date	J.D. G.M.T	Pg. Mag.	Plate No.	Astron. Date	J.D. G.M.T.	Pg. Mag.
	1926	2424000+			1926	2424000+	
116	May 8	644.9448	8.51	177	May 12	.9394	8.25
117		.9635	8.37	178		.9429	8.22
120	May 9	645.7590	8.08	179		.9463	8.14
121		.7631	8.15	180		.9498	8.17
122		.7666	8.09	181		.9533	8.20
123		.7700	8.13	182		.9567	8.26
124		.7735	8.18	183		.9602	8.21
125		.7770	8.11	184		.9637	8.15
126		.7805	8.08	185		.9672	8.26
127		.7839	8.20	186		.9706	8.22
128		.7874	8.23	187		.9741	8.26
129		.7909	8.16	188		.9776	8.32
130		.7943	8.34	189		.9811	8.20
131		.7878	8.39	190		.9845	8.36
132		.8013	8.36	191		.9880	8.34
133		.8048	8.34	192		.9915	8.22
134		.8082	8.45	193		....	Rejected
135		.8117	8.38	203	June 13	680.6958	8.27
136		.8152	8.37	204		.7132	8.32
137		.8187	8.39	205		.7166	8.35
138		.8221	8.43	206		.7201	8.37
139		.8256	8.35	207		.7236	8.33
140		.8659	8.14	208		.7270	8.43
141		.8693	8.13	209		.7305	8.45
142		.8728	8.08	210		.7340	8.47
143		.8763	8.11	211		.7375	8.52
144		.8798	8.23	212		.7409	8.48
145		.8832	8.13	213		.7444	8.56
146		.8867	8.11	214		.7479	8.55
147		.8902	8.13	215		.7514	8.53
148		.8937	8.19	216		.7548	8.53
149		.8971	8.10	217		.7583	8.48
150		.9006	8.14	218		.7618	8.43
151		.9041	8.25	219		.7652	8.40
152		.9075	8.21	220		.7687	8.36
153		.9110	8.26	221		.7722	8.37
154		.9145	8.24	222		.7757	8.33
155		.9180	8.26	223		.7791	8.29
162	May 12	648.8873	8.44	224		.7826	8.27
163		.8908	8.44	225		.7861	8.25
164		.8942	8.33	226		.7896	8.13
165		.8977	8.33	227		.7930	8.24
166		.9012	8.41	228		.7965	8.05
167		.9047	8.32	229		.8000	8.12
168		.9081	8.24	230		.8034	8.25
169		.9116	8.36	231		.8069	8.12
170		.9151	8.26	232		.8104	8.27
171		.9185	8.22	233		.8139	8.15
172		.9220	8.22	234		.8173	8.13
173		.9255	8.20	235		.8208	8.13
174		.9290	8.13	236		.8243	8.25
175		.9324	8.15	237		.8277	8.12
176		.9359	8.22	238		.8313	8.17

during three runs. Each plate has one exposure of 3 minutes,[1] and, as a rule, the beginning of successive exposures is every fifth minute. The plates used were Eastman 40 for the May runs and Eastman 33 for the series of June 13. The use of a separate plate for each exposure has the advantage that no systematic plate errors occur. The variable and five comparison stars have been measured with the thermopile photometer. One plate was rejected. Separate reduction

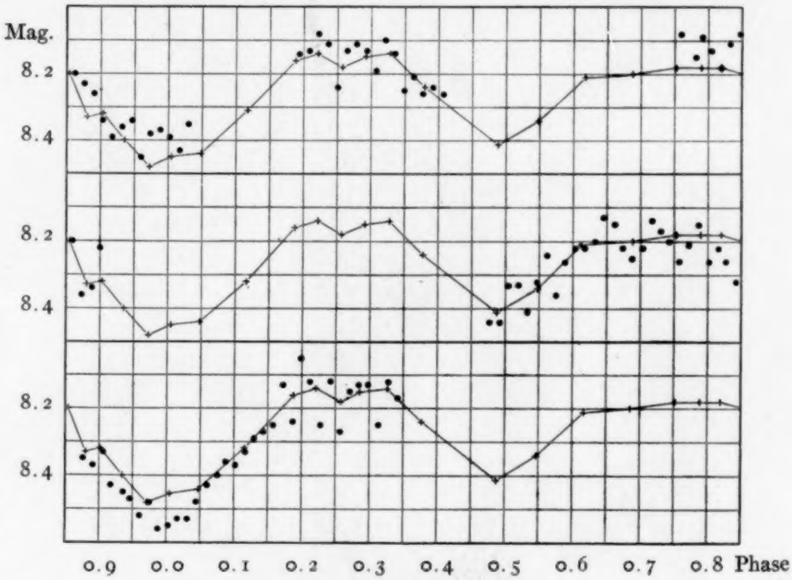


FIG 2.—B. D.+75° 752

curves have been drawn for all the plates. The comparison stars are given in Table III. The adopted magnitudes are smoothed values derived from measures on the plates.

The results of the measurements are given in Table IV. The times of mid-exposure are given in J.D. G.M.T. not reduced to the sun. The three main runs of observations are represented graphically in Figure 2, which shows that the variable is of the type of W Ursae Majoris.

The provisional interval of 0.123 day from minimum to minimum gives a revolution time of only 5^h54^m, which is three-fourths of the

[1] Plates 116 and 117 had an exposure time of 5^m.

period of W Ursae Majoris. The maximum brightness is 8.13, and the depth of the minimum 0.35 mag. There is some uncertainty in the number of epochs[1] between the two minima of May 9 and June 13, and, on this account, the phases are not printed in Table IV. The number adopted is 284 (number of half-periods), which fits all of the

TABLE V

NORMAL POINTS FOR B.D.$+75°752$

Phase	Pg. Mag.	Phase	Pg. Mag.	Phase	Pg. Mag.
0.005	8.45	0.328	8.14	0.790	8.18
.048	8.44	.378	8.24	.820	8.18
.116	8.32	.488	8.41	.854	8.20
.188	8.16	.548	8.34	.880	8.33
.222	8.14	.617	8.21	.903	8.32
.257	8.18	.688	8.20	.935	8.40
0.292	8.15	0.753	8.18	0.972	8.48

observations. The revolution period thus derived is 0.2460 ± 0.0002 day, the reciprocal of which has been used for the computation of the normal points. These are given in Table V, and are shown graphically in Figure 2 by the broken lines. The minima occur at phases 0.99P and 0.49P, whence the elements are:

$$\text{Min. J.D. G.M.T. } 2424680.744 + 0.2460\,E.$$
$$\pm 0.0003 \pm 0.0002 \text{ (m.e.)} .$$

Attention may be called to the large proper motion, viz., $+0\overset{s}{.}0895$ and $+0\overset{''}{.}531$. The trigonometric parallax, the mean of the determinations at Greenwich and Yale, is $0\overset{''}{.}044$.

MOUNT WILSON OBSERVATORY
July 1926

[1] The uncertainty as to the period has been much decreased by a minimum observed by Mr. van Gent at Leiden, which Professor Hertzsprung kindly communicated. This minimum, June 28, 1926, G.M.T. 11^h49^m7, occurs at phase 0.945P.

THE ABSOLUTE MAGNITUDES AND PARALLAXES OF 410 STARS OF TYPE M[1]

By WALTER S. ADAMS, ALFRED H. JOY, and M. L. HUMASON

ABSTRACT

Spectroscopic absolute magnitudes of M stars.—Magnitudes and *spectral types* have been determined for 410 M-type stars (Table I). Nearly all Boss stars north of $-30°$, several stars from the Selected Areas, and about 100 dwarf stars of this type have been included. The stars were classified from Mo to M7 on the basis of the titanium bands.

The *absolute magnitudes* were determined according to methods previously employed with the aid of additional lines and *new reduction curves*. λλ 4077, 4207, 4215, 4258, $H\gamma$, 4389, 4489, and $H\beta$ were used for *giants* and λλ 4318, 4435, 4454, 4535, 4586, and 4607 for *dwarfs*. The reduction curves were calibrated with the aid of mean parallaxes derived from *peculiar motions* for the giants and *trigonometric parallaxes* for the dwarfs.

Twenty-eight stars are brighter than -1.0 mag. and are called "super-giants." The ordinary giants show very little dispersion in absolute magnitude. The dwarfs vary with advancing type from $+7.0$ to $+12.5$ mag. Figures 1 and 2 indicate the relationship between type and absolute magnitude.

The mean difference between the spectroscopic and the trigonometric parallaxes is less than 0".001 for 71 giants. For dwarfs the mean difference is 0".002. The absolute magnitudes of 165 giants average 0.4 mag. brighter than those previously published in a list of 1646 stars. A comparison with Young and Harper, and with Rimmer, shows the Mount Wilson values to be fainter by 0.8 and 0.7 mag., respectively.

During the past few years we have made a special study of the absolute magnitudes and spectral types of the stars of type M, including those with either giant or dwarf characteristics of spectrum. We have now completed observations of essentially all the stars of this type in Boss's *Catalogue* north of $-30°$ of declination. In addition we have included in our investigation numerous stars listed as K5 in the *Henry Draper Catalogue*, but classified as of type M according to our system, several stars observed in the Selected Areas, and about one hundred dwarf stars of the eighth and ninth magnitudes, visually. The dwarf stars were, of course, selected on the basis of proper motion, but no selection was made in the case of the giant stars except that of apparent magnitude.

The system of classification employed is that adopted by the International Astronomical Union on the recommendation of the Committee on the Spectral Classification of Stars. It is based almost entirely on the intensities of the bands of titanium oxide, only minor consideration being given to other features of the spectrum. The

[1] *Contributions from the Mount Wilson Observatory*, No. 319.

stars are listed as M0, M1, M2, etc., according to increasing intensities of these bands. It is well known that many of the long-period variable stars of class M show a much more advanced type of spectrum than the normal stars of this class. Accordingly, since the system of classification is designed to include these variables, no stars of type more advanced than M6 or M7 are found in our list. The great majority of the stars are of types M0–M4. In the case of the dwarf stars it seems probable that those of type later than M5 would be so faint apparently that they could hardly be observed under present conditions.[1]

The method of deriving the absolute magnitudes of the giant M-type stars listed in the catalogue of 1646 stars[2] published several years ago was described as a provisional one based on the comparison of the intensities of two or three pairs of lines with those of certain standard stars. With the increase in the amount of observational material it has become possible to calibrate new reduction curves for the separate spectral subdivisions by the aid of mean parallaxes derived from peculiar and parallactic motions. An examination of the spectra of some of the stars of exceptional absolute magnitude, such as α Orionis for example, has increased the list of lines suitable for determinations of absolute magnitude and should add materially to the accuracy of the values. For giant M stars the low-temperature lines of iron at $\lambda\lambda$ 4207, 4258, 4389, and 4489, together with the hydrogen lines $H\gamma$ and $H\beta$, and the ionized strontium line at λ 4077, have proved most useful. The ionized strontium line at λ 4215 has been used occasionally but is complicated by the presence of a low-temperature iron line nearby. For dwarf stars calcium lines at $\lambda\lambda$ 4318, 4435, 4454, and 4586, the titanium blend at λ 4535, and the low-temperature strontium line at λ 4607 have been used successfully. The calibration of the reduction curves for the dwarf stars has been made by the aid of trigonometric parallaxes which give by far the most accurate values for such stars.

The determination of the preliminary reduction curves for the individual lines in the spectra of giant stars was made about a year ago and was based upon mean parallaxes derived from the paral-

[1] *Publications of the Astronomical Society of the Pacific*, **37**, 157, 1925.

[2] *Mt. Wilson Contr.*, No. 199; *Astrophysical Journal*, **53**, 13, 1921.

lactic and peculiar motions of the stars observed up to that time. Since the radial velocities of these stars are fairly large on the average, the values derived from the peculiar motions were assigned a much higher weight in the solution. Trigonometric parallaxes were not used in this calibration. Preliminary values of the absolute magnitudes of all the stars in the list were determined from the reduction curves obtained in this way, and then the entire material was rediscussed and the corrections to the preliminary system were calculated. The method is simply one of successive approximations. In nearly all cases the corrections were found to be a few tenths of a unit in absolute magnitude, the largest values applying to the brightest stars or "super-giants," for which the material available for calculating mean parallaxes is necessarily scanty. The corrections derived from the final computation were then applied to the preliminary values, and the resulting absolute magnitudes are those listed in our Table I. The extensive calculations involved in the determination of the mean parallaxes were carried out by Dr. Strömberg, to whom we are indebted most deeply.

The method used by Strömberg in deriving the corrections to the provisional system of absolute magnitudes was to divide the stars into groups of different absolute magnitude (as based on the provisional values) and different spectral subdivisions, and to calculate the average peculiar radial velocity θ and the solar motion from the radial velocities of the stars in each group. The peculiar motions were found to give very consistent results for the mean parallaxes computed from the proper motions in right ascension and declination as well as from the τ-component. The values of θ vary but little, in general less than 0.5 km/sec., so that the mean parallaxes derived from the peculiar motions appear to be very reliable. They have been corrected for a mean error of $\pm 0\overset{''}{.}004$ in the proper-motion components, but even were the error twice as great, the effect upon the absolute magnitudes would be small.

On the other hand, the mean parallaxes of these groups of stars derived from parallactic motions are very uncertain, the results from proper motion in right ascension and declination differing by as much as $0\overset{''}{.}004$ in some cases. The mean parallaxes from parallactic motions are systematically smaller than those derived from peculiar

motions, the difference being 0″.0022 for the group of brightest stars, and 0″.0016 for the ordinary giants. These would correspond to differences of 1.0 and 0.5 in mean absolute magnitude. No explanation can as yet be given for this discrepancy which has been found to exist in the case of some other stars, such, for example, as the long-period variables. Because of the uncertainty in the values derived from parallactic motions, the mean parallaxes and absolute magnitudes calculated from peculiar motions have been used exclusively in calibrating our final reduction curves, and this consideration should be borne in mind in making comparisons between our results and those of other observers who have used mean parallaxes based largely upon parallactic motions.

The successive columns of Table I give the data for the stars observed. Those listed in Boss's *Preliminary General Catalogue* are given by number with no further designation. Because of the convenience and accessibility of Porter's "Catalogue of Proper Motion Stars," *Publications of the Cincinnati Observatory*, No. 18, most of the dwarf stars have been listed according to their numbers in this catalogue. The visual apparent magnitudes are given under m, the values being taken, where possible, from the *Henry Draper Catalogue*. The spectral types are the means of our own determinations, and the total proper motions μ are mainly from the catalogues of Boss and Porter. The remaining columns give the absolute magnitudes M, the corresponding parallaxes, and the trigonometric parallaxes compiled by Schlesinger in his *Catalogue of Parallaxes*, 1924.

Although for the sake of uniformity all the spectroscopic parallaxes have been given to three places of decimals, attention should be called to the very marked difference in the influence of an uncertainty in the absolute magnitude on the parallaxes of giants as compared with dwarf stars. As an illustration, if we select two adjacent stars in the list, Boss 40 and Cin. 25, we find that an error of 0.3 in the absolute magnitude would affect the parallax of Boss 40 by 0″.0005 and that of Cin. 25 by 0″.043. The apparent magnitudes of the fainter dwarf stars, and especially of the components of visual binaries, are also subject to serious uncertainties which enter directly into the calculation of the spectroscopic parallaxes. Additional photometric observations of these stars would be of great value.

TABLE I

Name	α 1925	δ 1925	m	Sp.	μ	M	Spec. π	Trig. π
Comp. Lal. 47231	0^h $0^m.7$	+45° 23′	10.2	M2	0″.856	+10.6	0″.120	0″.097
Cin. 3161	0 0.8	−37 43	8.3	M3	6.112	+10.0	.219	.220
Lal. 47231 Br.	0 1.2	+45 24	8.6	M0	0.858	+ 8.7	.105	.097
B.D. +61°8	0 5.6	+62 14	9.2	M2ep	......	− 1.3	.001	......
B.D. +75°4	0 9.8	+75 37	7.6	M4	......	− 0.2	.003	......
30	0 10.6	− 8 12	5.4	M4	.060	− 0.2	.008	......
31	0 10.7	+19 47	4.9	M1	.094	+ 0.7	.014	− .009
33	0 10.8	−19 21	4.7	M1	.068	− 0.1	.011	......
40	0 12.8	+ 1 26	7.3	M5	0.022	− 0.2	.003	......
Cin. 25	0 14.0	+43 36	8.1	M2	2.890	+10.4	.288	.282
Comp. Cin. 25	0 14.0	+43 36	10.5	M5	2.890	+12.4	.240	.282
64	0 19.3	−16 22	6.6	M3	0.041	− 0.1	.005	......
B.D. +30°59	0 23.2	+30 46	7.6	M1	......	0.0	.003	......
81	0 24.1	+17 29	5.3	M3	.117	− 0.6	.007	......
90	0 26.2	− 4 22	6.0	M0	0.011	+ 0.2	.007	......
B.D. +66°34	0 27.6	+66 51	9.5	M3	1.775	+ 8.7	.069	......
βG.C. 368 Ft.	0 37.0	− 7 38	10.0	M1	0.022	+ 7.6	.033	......
B.D.+45°181	0 38.7	+45 31	7.4	M0	......	+ 0.2	.004	......
161	0 42.6	+15 4	5.6	M4	0.064	+ 0.1	.008	.013
168 Ft.	0 44.5	+57 25	7.4	M0	1.242	+ 8.2	.145	.182
191	0 49.2	− 1 33	4.9	M0	0.017	− 0.2	.010	......
217	0 55.9	+ 6 5	6.3	M1	0.023	− 0.9	.004	− .002
B.D.+63°137	1 1.9	+63 32	8.7	M1	1.55	+ 8.5	.091	.078
259	1 5.5	+35 13	2.4	M0	0.216	+ 0.3	.038	.045
274	1 8.2	+44 56	6.6	M1	.042	+ 0.2	.005	......
B.D.+55°290	1 14.7	+55 56	8.9	M6	......	0.0	.002	......
306	1 18.7	+ 1 20	6.5	M0	.069	0.0	.005	......
342	1 30.7	+18 5	6.0	M2	.088	+ 0.3	.007	......
Cin. 238	1 38.5	+63 28	8.2	M0	.70	+ 8.2	.100	0.082
B.D.+55°394	1 39.3	+56 9	9.0	M0	......	− 0.5	.001	......
Cin. 251	1 49.2	−22 49	8.9	M1	.857	+ 9.0	.105	......
451	1 56.2	−21 11	5.7	M1	.014	+ 0.1	.008	......
453	1 56.5	−21 26	4.2	M1	.130	+ 0.2	.016	......
455	1 56.7	− 8 53	5.7	M5	.086	0.0	.007	......
491	2 6.5	+19 9	5.9	M3	.092	− 0.1	.006	......
502	2 8.9	+14 56	6.0	M1	.100	+ 0.1	.007	......
B.D.+56°547	2 15.3	+56 39	8.2	M3	......	− 1.4	.001	......
B.D.+56°551	2 15.8	+56 49	8.2	M0	......	− 1.4	.001	......
B.D.+57°550	2 16.5	+57 31	8.6	M2	......	− 1.4	.001	......
B.D.+55°597	2 16.9	+56 16	8.2	M4	......	− 1.3	.001	......
B.D.+56°583	2 17.2	+56 46	7.0	M6	......	− 0.7	.003	......
B.D.+56°595	2 18.0	+56 51	8.5	M1	......	− 1.8	.001	......
539	2 18.1	+ 0 3	5.9	M1	0.006	0.0	.007	......
B.D.+56°597	2 18.2	+56 52	8.6	M0	......	− 1.7	.001	......
B.D.+56°609	2 20.1	+57 6	8.5	M4	......	− 1.1	0.001	......

TABLE I—*Continued*

Name	α 1925	δ 1925	m	Sp.	μ	M	Spec. π	Trig. π
570....	$2^{h}27^{m}2$	−22° 53′	6.4	M2	0".044	+ 0.1	0".005	....
582....	2 31.2	+34 22	5.6	M3	.061	− 0.3	.007	0".012
617 Ft..	2 39.1	+48 55	10.0	M2	.351	+ 8.2	.044	.080
646....	2 46.9	+34 45	4.7	M0	.077	+ 0.3	.013	.009
βG.C. 1490 Ft..	2 51.2	+26 34	9.7	M1	.333	+ 8.7	.063	.060
660....	2 51.6	+18 2	5.9	M6	.018	0.0	.007	.012
669....	2 56.0	+79 7	5.7	M2	.039	0.0	.007	....
691....	2 58.4	+ 3 48	2.8	M2	.078	+ 0.1	.029	.011
698....	3 0.4	+38 33	3.7	M4	.173	− 0.7	.013	.038
B.D. +1°543....	3 2.7	+ 1 42	8.9	M0	.91	+ 8.4	.079	....
707....	3 2.8	− 6 23	5.6	M3	.002	0.0	.008	....
712....	3 4.1	+18 30	6.5	M0	.042	+ 0.5	.006	.028
759....	3 16.2	−22 2	4.0	M3	.065	− 0.3	.014	....
765....	3 18.1	+64 19	5.6	M0	.019	− 1.8	.003	....
Cin. 456....	3 24.4	−20 4	8.2	M0	.603	+ 8.7	.126	....
826....	3 35.6	+62 59	5.3	M4	.022	− 0.6	.007	....
B.D.+68°278....	3 40.5	+68 26	9.2	M1	.30	+ 7.8	.052	.073
868....	3 42.5	−12 20	4.6	M2	.069	0.0	.012	....
864....	3 42.6	+65 18	4.7	M1	.004	− 1.1	.007	....
912....	3 52.9	−13 49	6.7	M2	.010	− 0.7	.003	....
915....	3 54.5	−13 43	3.2	M0	0.130	− 0.2	.021	.018
o Eridani C......	4 11.8	− 7 46	10.8	M6e	4.082	+11.9	.166	.203
993...	4 15.3	+60 34	5.7	M0	0.122	− 0.3	.006	....
1014...	4 17.9	+20 39	6.1	M0	.011	0.0	.006	− .003
1057...	4 26.8	+14 57	6.6	M3	.074	− 0.1	.005	....
1071...	4 30.6	− 8 23	5.4	M3	.035	− 0.6	.006	....
Cin. 594...	4 31.7	+52 45	8.5	M2	.53	+ 9.0	.126	.091
1105...	4 37.2	−19 49	4.5	M3	.094	+ 0.1	.013	....
1128...	4 45.1	+63 23	5.8	M2	.111	0.0	.007	.002
1149...	4 48.3	+14 8	5.2	M4	.059	− 0.4	.008	....
1154...	4 49.5	+ 2 23	5.7	M1	.034	0.0	.007	.006
B.D.+42°1180...	5 3.5	+42 28	8.8	M6	......	0.0	.002	....
1237...	5 7.9	−11 56	5.9	M6	.051	− 0.8	.005	....
Comp. 1246...	5 11.2	+45 55	10.0	M2	.437	+ 9.6	.083	.069
1256...	5 12.9	+42 43	5.9	M4	.049	− 0.4	.005	.004
B.D.+29° 897...	5 22.4	+29 52	8.0	M1	......	− 2.4	.001	....
1309...	5 23.1	+63 0	5.8	M1	.005	− 0.3	.006	....
1327...	5 25.9	− 1 9	5.0	M0	0.028	0.0	.010	....
Cin. 705...	5 27.6	− 3 40	8.8	M3	2.222	+10.2	.190	0.172
1335...	5 27.8	+18 32	4.7	M2	0.013	− 3.0	.003	....
1334...	5 29.7	+75 0	6.4	M0	.019	0.0	.005	....
1348...	5 30.4	+54 23	6.0	M0	.007	− 0.2	.006	....
B.D.+43°1332...	5 38.1	+43 28	8.8	M1	.004	− 0.4	.001	....
1439...	5 45.9	+37 17	5.0	M1	0.052	+ 0.3	.011	....
B.D.+27° 887...	5 46.1	+27 40	7.7	M5	......	+ 0.1	0.003	....

TABLE I—*Continued*

Name	α 1925	δ 1925	m	Sp.	μ	M	Spec. π	Trig. π
M 37, Br. star....	5^h47^m3	+32° 32′	9.7	M1	0″.007	− 0.1	0″.001	....
1468...	5 51.1	+ 7 24	0.9	M2	.029	− 4.3	.009	0″.017
1479...	5 54.4	+45 56	4.6	M3	.011	− 1.0	.008	....
1531...	6 4.4	−19 9	5.5	M2	.063	− 0.6	.006	....
B.D.+23°1243...	6 7.4	+23 14	7.4	M3ep	......	− 1.3	.002	....
1549...	6 7.8	+22 56	6.3	M2	.027	− 1.4	.003	.000
1561...	6 10.4	+22 32	3.8	M3	.065	− 0.4	.014	.014
1560...	6 11.0	+61 33	5.3	M3	.005	− 0.6	.007	....
1596...	6 15.8	+14 41	6.0	M0	.019	0.0	.006	....
1599...	6 16.2	− 2 55	5.2	M1	.009	0.0	.009	− .004
βG.C. 3319 Br.	6 16.8	+ 5 47	8.1	M4	......	− 0.1	.002	.001
1604...	6 18.4	+22 33	3.2	M3	.128	− 0.4	.019	.016
1606...	6 19.1	+49 20	5.1	M0	.014	− 2.7	.003	.000
B.D.+17°1320...	6 32.9	+17 37	9.5	M1	.88	+ 9.1	.083	.097
B.D.+45°1330...	6 33.2	+45 8	8.8	M2	......	+ 0.2	.002	....
1715...	6 38.4	− 9 6	5.3	M0	.037	+ 0.3	.010	....
1743...	6 44.0	− 8 55	5.3	M1	.036	− 2.1	.003	....
Cin. 837...	6 51.2	+40 11	8.3	M0	.43	+ 7.5	.069	.030
1808...	6 58.3	− 5 37	5.4	M2	.009	− 0.6	.006	....
1810...	6 58.7	−27 50	3.7	M0	.011	− 2.1	.007	....
1801...	7 5.9	+87 10	5.3	M2	.051	0.0	.009	....
1846...	7 7.5	+51 33	5.7	M3	.019	+ 0.2	.008	.003
1856...	7 9.1	+16 17	5.3	M4	.051	− 0.4	.007	.004
1861...	7 10.1	+25 1	6.0	M1	.105	+ 0.3	.007	....
1868...	7 11.3	+28 2	5.9	M1	.020	+ 0.1	.007	.004
1887...	7 13.5	−23 11	4.8	M0	.001	− 2.2	.004	....
1889...	7 13.6	−27 45	4.8	M3	.045	− 0.2	.010	....
B.D.+33°1505...	7 14.6	+32 59	9.3	M1	.57	+ 8.9	.079	....
1871...	7 15.4	+82 34	5.1	M4	.045	− 0.1	.009	....
1918...	7 18.0	−25 45	6.1	M5	.031	0.0	.006	....
Comp. 1979...	7 29.8	+32 3	9.6	M1e	.203	+ 8.8	.069	.076
1985...	7 30.4	−14 22	5.1	M3ep	.016	− 1.5	.005	....
1986...	7 31.1	+46 21	5.8	M1	.047	+ 0.2	.008	....
1987...	7 31.3	+27 4	4.2	M0	.119	+ 0.1	.015	.011
2005...	7 35.1	+17 51	5.2	M0	.004	− 0.3	.008	.000
2020...	7 37.8	+14 23	5.8	M3	.015	− 0.8	.005	.002
2028...	7 39.5	+25 58	5.4	M0	.034	0.0	.008	....
2037...	7 41.7	+37 42	5.4	M3	.030	0.0	.008	....
2049...	7 42.7	+33 36	5.3	M1	.040	− 0.1	.008	.010
2144...	8 1.9	+22 51	6.2	M3	.024	− 0.5	.005	....
2186...	8 12.5	+72 39	6.2	M0	.027	0.0	.006	....
2223...	8 19.8	+10 53	6.3	M2	.021	+ 0.4	.007	....
2245...	8 22.6	+12 54	5.8	M3	.116	− 0.9	.005	.025
2265...	8 27.3	+18 21	5.6	M1	0.087	+ 0.3	.009	....
B.D.+67° 552...	8 29.8	+67 33	9.3	M0	1.101	+ 7.9	0.052	0.085

TABLE I—*Continued*

Name	α 1925	δ 1925	m	Sp.	μ	M	Spec. π	Trig. π
2378...	8^h48^m0	+28° 33′	6.3	M3	0″.022	− 0.5	0″.004	−0″.003
βG.C. 4815 Br.	8 48.5	+71 5	8.6	M1	1.390	+ 8.4	.091	.086
βG.C. 4815 Ft.	8 48.5	+71 5	8.7	M1	1.390	+ 8.4	.087	.086
2404BC.	8 54.1	+48 20	9.5	M2	0.504	+ 7.8	.046	.070
2410...	8 54.9	+18 26	6.6	M4	.089	0.0	.005	......
2411...	8 55.8	+67 55	5.0	M3	.021	+ 0.1	.010	......
B.D.−32°6877...	9 1.4	−32 8	7.7	M5	......	+ 0.2	.003	......
2434...	9 1.8	+67 11	5.3	Mo	.050	− 0.1	.008	......
2450...	9 4.7	−25 33	4.8	M1	0.040	− 0.6	.008	......
2469...	9 9.3	+53 1	8.1	Mo	1.677	+ 9.3	.174	.165
2470...	9 9.3	+53 1	8.1	Mo	1.686	+ 9.0	.151	.165
2474...	9 10.3	+57 3	5.5	Mo	0.036	0.0	.008	......
2507...	9 16.5	+34 43	3.3	Mo	.216	− 0.3	.019	.002
B.D.+81° 297...	9 17.6	+80 55	9.0	Mo	.442	+ 7.1	.042	.058
2516...	9 18.2	−25 39	4.9	M1	.022	+ 0.4	.013	......
2546...	9 27.0	+35 26	5.5	M1	.130	+ 0.2	.009	......
B.D.+36°1970...	9 27.3	+36 40	9.3	M2	.56	+ 9.0	.087	......
B.D. +8°2243...	9 30.7	+ 8 33	8.1	M3	.019	− 0.3	.002	......
2578...	9 32.3	+31 30	5.7	M2	.044	− 0.1	.007	......
2612...	9 39.7	+14 22	5.6	M2	.014	− 0.1	.007	......
2614...	9 41.2	+57 28	5.4	M3	.025	− 0.9	.005	......
2621...	9 42.2	+ 7 3	6.0	M1	.040	0.0	.006	......
2633...	9 45.6	+39 59	6.8	M2	.016	− 0.2	.004	......
2639...	9 47.0	+13 25	6.7	Mo	0.037	− 0.3	.004	......
Cin. 1167...	9 47.4	−11 55	9.4	M2	1.848	+ 9.3	.096	.080
B.D.+63° 869...	9 50.6	+63 9	8.5	M1	0.600	+ 9.0	.126	......
2658...	9 51.3	−18 39	5.2	M1	.050	+ 0.3	.010	......
2680...	9 56.3	+ 8 24	4.9	M2	0.043	0.0	.010	......
Cin. 1218...	10 6.8	+49 51	6.8	Mo	1.451	+ 8.3	.200	.178
Cin. 1225...	10 9.1	+52 55	9.0	Mo	0.74	+ 7.8	.058	.073
2731...	10 12.7	+14 6	5.7	M2	.035	+ 0.4	.009	......
Cin. 1244...	10 15.6	+20 15	9.0	M4e	.490	+11.2	.275	.207
Cin. 1246...	10 16.9	− 1 5	8.9	Mo	.679	+ 7.0	.042	......
2766...	10 21.3	+ 9 10	5.9	M3	.045	+ 0.1	.007	......
2770...	10 22.0	− 6 41	5.8	M2	.189	0.0	.007	......
B.D.+46°1635...	10 27.0	+45 55	8.8	Mo	.837	+ 8.2	.076	......
2796...	10 27.2	− 7 15	6.4	Mo	.045	+ 0.6	.007	......
2800...	10 28.2	+14 31	5.7	M2	.041	− 0.2	.007	− .004
2821...	10 32.6	−15 57	6.2	M1	.027	− 0.5	.007	......
2847...	10 38.0	+32 5	6.3	M6	.030	+ 0.1	.006	......
2865...	10 41.7	+57 46	6.5	M2	.081	+ 0.5	.006	......
2915...	10 52.1	+ 6 35	6.0	M5	.023	− 0.6	.005	− .009
2921...	10 55.4	+36 30	6.2	M2	.095	+ 0.1	.006	.019
2931...	10 58.0	− 2 5	5.0	M1	0.041	+ 0.2	.011	......
2935...	10 59.3	+36 28	7.6	M2	4.778	+10.4	0.363	0.392

TABLE I—*Continued*

Name	α 1925	δ 1925	m	Sp.	μ	M	Spec. π	Trig. π
Lal. 21258...	11h 1m.9	+43° 54′	8.9	M2	4″.519	+10.1	0″.174	0″.177
Lal. 21368A..	11 6.9	+30 52	8.8	M1	0.623	+ 8.6	.091	.085
Lal. 21368B..	11 6.9	+30 52	9.8	M2	.623	+10.3	.126	.085
Cin. 1364...	11 7.7	−14 34	9.3	Mo	.92	+ 8.0	.055	....
2976...	11 11.2	+23 30	4.9	M2	.018	− 0.8	.007	....
2983...	11 13.4	+ 2 25	5.4	Mo	.159	+ 0.6	.011	....
Cin. 1375...	11 13.5	− 1 35	8.8	Mo	0.53	+ 7.7	.060	....
Cin. 1383...	11 16.4	+66 15	9.2	M2	2.986	+ 9.0	.091	.126
3002...	11 20.8	−10 27	5.1	M1	0.043	− 0.1	.009	....
3031...	11 27.0	+69 45	4.1	Mo	.045	− 0.2	.014	.022
3067...	11 34.6	+ 8 33	5.5	M6	.013	+ 0.3	.009	....
B.D.+45°1955...	11 37.7	+44 37	7.8	M3	.021	+ 0.1	.003	....
3089...	11 42.0	+ 6 57	4.2	M1	.188	− 0.2	.013	.007
3100...	11 44.9	−26 20	5.4	M4	.028	− 0.3	.007	....
3128...	11 54.4	+ 3 54	7.0	M4	.009	− 0.2	.004	....
3136...	11 56.4	+81 16	6.4	M4	.068	− 0.8	.004	....
B.D.+30°2217...	11 59.7	+30 6	7.7	M5	......	0.0	.003	....
Cin. 1551...	12 18.2	+42 33	9.1	M1	.57	+ 8.9	.091	....
3234...	12 21.5	+57 12	6.0	M3	.028	+ 0.4	.008	....
3248...	12 24.0	+56 8	5.8	M2	.031	+ 0.6	.009	....
3252...	12 25.2	− 2 1	7.6	M4	.049	+ 0.1	.003	....
3259...	12 26.4	−23 17	5.9	Mo	.030	− 0.5	.005	....
3265...	12 26.8	+69 37	5.2	M4	.084	− 0.3	.008	....
B.D. +9°2636...	12 27.5	+ 9 14	8.8	M1	.96	+ 8.6	.091	....
3294...	12 34.6	+ 2 16	6.0	M3	.090	+ 0.2	.007	....
3295...	12 34.9	− 3 58	6.9	Mo	.053	+ 0.1	.004	....
3331...	12 44.0	+ 3 59	6.7	M4	.013	+ 0.3	.005	....
Cin. 1633...	12 46.9	− 0 21	8.7	Mo	.393	+ 8.7	.100	....
3348...	12 48.5	+17 29	6.5	Mo	.023	− 0.3	.004	.022
3362...	12 50.5	− 9 8	4.9	M3	.032	− 0.3	.009	....
3367...	12 51.8	+ 3 48	3.7	M3	.479	0.0	.018	.010
3374...	12 55.2	+17 49	5.0	Mo	.036	+ 0.1	.010	....
Cin. 1661...	12 56.5	− 2 18	9.5	Mo	.73	+ 8.3	.058	....
3398...	13 2.7	+23 1	5.9	M5	.066	− 0.2	.006	.032
B.D.+18°2696...	13 5.8	+17 52	8.7	Mo	.120	+ 0.0	.002	− .010
3434...	13 10.8	+11 44	5.8	Mo	.090	0.0	.007	....
3446...	13 13.8	+ 5 52	5.0	M2	.016	− 0.2	.009	....
Cin. 1719...	13 16.1	+35 31	9.0	M2	.884	+ 9.1	.105	.085
3460...	13 18.2	−12 11	7.1	M2	.027	0.0	.004	....
βG.C. 6476S..	13 20.1	+29 36	9.4	Mo	.535	+ 8.4	.063	....
3488...	13 24.2	+72 47	6.1	M1	.030	− 0.5	.005	....
3499...	13 28.1	− 5 52	4.8	M3	.112	+ 0.2	.012	....
3534...	13 37.7	− 8 20	5.2	M2	.108	+ 0.1	.010	....
3536...	13 37.9	+55 4	4.8	M2	0.028	+ 0.1	.011	....
Cin. 1784...	13 41.4	+18 13	9.6	M1	1.86	+ 9.3	0.087	0.079

TABLE I—*Continued*

Name	α 1925	δ 1925	*m*	Sp.	μ	*M*	Spec. π	Trig. π
Cin. 1786...	13h41m9	+15° 18′	8.5	M2	2″298	+10.2	0″219	0″185
3553...	13 43.3	−17 29	5.8	M2	0.065	− 0.7	.005	....
3572...	13 45.9	+16 10	4.3	Mo	.106	+ 0.6	.018	....
3581...	13 47.8	+35 2	6.0	M1	.072	0.0	.006	.001
3584...	13 48.5	+34 49	5.0	M2	.044	− 0.3	.009	....
3589...	13 49.3	+65 6	4.8	M3	.004	− 0.4	.009	....
βG.C. 6710N..	13 59.5	+46 42	9.5	M4	.609	+ 9.9	.120	....
B.D.+29°2486...	14 1.1	+29 30	8.2	M3	......	0.0	.002	....
3630...	14 4.9	+44 13	5.4	M4	.037	− 0.7	.006	....
3631...	14 5.5	+49 49	5.4	M2	.068	0.0	.008	....
3632...	14 6.7	−15 57	5.1	M3	.027	− 0.6	.007	....
3656...	14 10.7	+69 47	5.4	M2	.068	+ 0.4	.010	....
B.D.+15°2690...	14 13.9	+15 36	6.0	M3	......	0.0	.006	....
Cin. 1885...	14 18.8	+29 59	8.6	Mo	0.727	+ 8.1	.079	.067
Cin. 1894...	14 22.2	+23 59	9.5	M2	1.39	+ 8.7	.069	.053
Cin. 1895...	14 22.3	+24 0	9.6	M2	1.40	+ 9.1	.079	.053
B.D. −7°3856...	14 26.9	− 8 18	9.3	Mo	1.26	+ 8.7	.076	....
Cin. 1920...	14 31.9	+34 4	9.0	Mo	0.76	+ 8.5	.079	....
3733...	14 32.0	+49 42	5.9	M1	.067	− 0.2	.006	....
3761...	14 40.1	+26 51	4.9	M3	.024	− 0.5	.008	....
B.D.+34°2559...	14 42.1	+34 41	7.8	M2	0.044	− 0.3	.002	....
3812...	14 53.1	−21 4	8.9	M2	1.916	+ 9.4	.126	.182
3827...	14 56.4	+66 14	4.9	M5	0.082	0.0	.010	....
Cin. 1989...	14 56.7	−10 50	10.0	Mo	.467	+ 9.0	.063	....
3828...	14 57.4	− 2 28	5.7	M1	.048	0.0	.007	....
3831...	14 58.0	+ 0 9	5.9	M2	.030	− 0.9	.004	....
3837...	14 59.7	−24 59	3.4	M4	.094	− 0.1	.020	....
B.D.+25°2874...	15 4.2	+25 13	9.2	Mo	.961	+ 8.3	.066	.070
3867...	15 8.7	+19 15	6.0	M4	.004	− 0.2	.006	− .007
B.D. −3°3746...	15 10.2	− 3 32	9.2	Mo	0.69	+ 8.2	.063	....
B.D. −7°4003...	15 15.6	− 7 26	9.2	M5	1.33	+11.8	.331	....
3931...	15 22.3	+15 41	5.5	M1	0.033	− 0.1	.008	....
3938...	15 24.4	+25 22	6.3	M1	.039	0.0	.005	....
3945...	15 28.2	+41 5	5.2	Mo	.018	− 0.1	.009	.023
3967...	15 32.5	+39 15	5.4	M2	.029	0.0	.008	....
3969...	15 33.0	+15 21	6.8	M6	.011	− 0.4	.004	....
3990...	15 37.6	−19 26	5.0	Mo	.127	+ 0.1	.010	....
4015...	15 45.4	+18 22	4.3	M1	.110	0.0	.014	....
Cin. 2124...	15 49.4	+74 39	9.3	Mo	.320	+ 8.4	.066	.034
4048...	15 51.3	+20 32	5.8	Mo	.083	− 0.7	.005	.029
4054...	15 52.1	+43 21	5.5	M3	.075	− 0.1	.008	0.022
4096...	16 3.6	−26 8	5.6	M2	.122	− 0.5	.006	....
B.D.+35°2774...	16 3.8	+34 51	9.5	M1	.64	+ 8.8	.072	....
4103...	16 4.8	+ 8 44	5.9	M3	.024	− 0.3	.006	....
4125...	16 8.5	+23 41	6.0	M4	0.028	− 0.3	0.005	....

TABLE I—*Continued*

Name	α 1925	δ 1925	m	Sp.	μ	M	Spec. π	Trig. π
4134...	16h 10m.4	− 3° 30′	3.0	M0	0″.161	0.0	0″.025	0″.040
B.D. +75°585...	16 13.1	+74 51	8.4	M5	......	+ 0.2	.002	....
4159...	16 16.0	+59 56	5.6	M4	.022	− 0.6	.006	....
Cin. 2184...	16 16.6	+67 25	8.9	M0	.505	+ 8.6	.087	.090
4173...	16 19.5	+33 58	5.4	M2	.049	0.0	.008	.017
4188...	16 23.7	− 7 26	5.4	M2	.176	− 0.1	.008	.012
4193...	16 24.8	−26 16	1.2	M1	0.034	− 3.5	.011	.026
B.D. −12°4523...	16 26.2	−12 28	9.5	M5	1.24	+11.8	.288	....
4201...	16 26.2	+42 3	5.0	M6	0.028	0.0	.010	....
4211...	16 28.7	+33 40	6.7	M0	.039	− 0.2	.004	....
4212...	16 29.1	+11 39	4.9	M0	.204	+ 0.1	.011	− .011
4242...	16 36.7	+49 4	5.1	M2	.044	0.0	.010	....
4262...	16 42.0	+15 53	5.8	M3	.054	− 0.1	.007	.015
4264...	16 42.2	+ 8 43	5.4	M1	.016	0.0	.008	....
Cin. 2238...	16 42.3	+33 38	8.6	M0	.37	+ 8.7	.105	.178
4286...	16 47.7	+27 56	5.9	M1	0.011	0.0	.007	....
Cin. 2251...	16 51.5	− 8 12	9.2	M4e	1.234	+10.5	.182	.148
B.D. +25°3173...	16 55.1	+25 53	9.4	M2	0.52	+ 9.1	.087	....
4318...	16 55.4	−24 59	5.9	M3	.022	+ 0.1	.007	....
4336...	16 59.7	+14 12	5.1	M3	.070	+ 0.2	.010	....
4343...	17 0.8	+35 31	6.8	M4	0.058	− 0.8	.003	.000
4342...	17 1.2	− 4 57	7.9	M0	1.464	+ 7.8	.096	.091
Wolf 636...	17 1.4	− 4 57	9.3	M3	1.465	+10.1	.145	....
4366...	17 8.9	+10 40	5.6	M2	0.036	− 0.4	.006	....
B.D. +45°2505...	17 9.9	+45 49	9.6	M4	1.590	+ 9.9	.115	....
B.D. +42°2810...	17 10.7	+42 26	9.6	M1	1.061	+ 8.7	.066	.030
4373...	17 11.2	+14 28	3.5	M5	0.030	− 1.6	.010	− .002
B.D. −15°4502...	17 12.0	−15 8	6.8	M1	......	− 1.1	.003	....
4400...	17 17.0	+18 8	5.2	M2	.051	− 0.2	.008	....
4408...	17 18.2	+46 19	5.8	M0	0.050	− 0.1	.007	....
Cin. 2347...	17 34.5	+18 36	9.1	M1	1.39	+ 9.1	.100	.135
Cin. 2354...	17 36.9	+68 25	9.1	M4	1.334	+ 9.8	.138	.213
B.D. +43°2796...	17 41.7	+43 26	9.5	M3	0.616	+ 9.5	.100	....
Boss 4497B..	17 43.5	+27 46	9.5	M4	.817	+10.0	.126	.111
4526...	17 52.6	−23 56	6.9	M1	.003	− 0.3	.004	....
B.D. +45°2627...	17 54.7	+45 22	6.2	M6	......	− 0.2	.005	....
4555...	17 57.8	+45 30	5.9	M0	.044	+ 0.2	.007	0.018
4578...	18 2.9	+22 13	5.3	M2	.023	− 0.2	.008	....
4606...	18 9.1	+31 23	5.0	M3	.018	0.0	.010	....
4617...	18 12.6	−36 47	3.2	M4	.216	+ 0.2	.025	....
4630...	18 16.9	−24 57	6.4	M5	.011	− 0.6	.004	....
4636...	18 17.1	+21 56	5.0	M0	.062	0.0	.010	....
4649...	18 19.0	+23 15	5.7	M0	.076	+ 0.2	.008	....
4653...	18 19.6	+49 5	5.1	M3	0.058	0.0	.010	....
B.D. +43°2970...	18 21.8	+43 52	7.0	M2	......	− 0.5	0.003	....

TABLE I—*Continued*

Name	α 1925	δ 1925	m	Sp.	μ	M	Spec. π	Trig. π
Cin. 2456 Br.	18h42m0	+59° 30′	8.8	M4	2″307	+10.9	0″263	0″287
Cin. 2456 Ft.	18 42.0	+59 30	9.3	M5	2.307	+11.9	.331	.287
Cin. 2463...	18 45.6	+17 22	9.0	M0	0.579	+ 8.5	.079	....
4800...	18 51.9	+36 48	4.5	M4	.010	− 1.4	.007	....
4971...	18 52.9	+89 2	6.6	M4	.029	− 0.4	.004	....
4814...	18 53.1	+43 51	4.4	M5	0.077	− 0.6	.010	.006
Cin. 2475...	18 54.3	+ 5 50	9.7	M2	1.247	+ 8.9	.069	.074
B.D.+30°3409...	19 2.1	+30 37	6.4	M2	......	0.0	.005	....
B.D.+29°3472...	19 2.9	+29 48	6.6	M1	......	0.0	.005	....
4877...	19 5.7	+39 2	7.6	M6	0.007	− 0.6	.002	....
4966...	19 22.6	+50 6	7.1	M7	.016	− 0.3	.003	....
4976...	19 25.6	+24 31	4.6	M1	.170	+ 0.3	.014	.013
4983...	19 26.7	− 2 57	5.2	M1	.016	− 0.2	.008	....
4993...	19 30.0	−24 1	6.7	M0	.004	0.0	.005	....
Cin. 2556...	19 30.9	+ 4 25	10.5	M1	.58	+ 8.6	.042	....
5043...	19 41.3	+41 36	6.0	M0	.017	0.0	.006	.000
5052...	19 44.0	+18 21	3.8	M2	.009	− 1.0	.011	.003
B.D.+44°3242...	19 44.1	+44 53	9.2	M2	......	+ 0.1	.002	....
5069...	19 47.9	+38 32	5.4	M2	.098	− 0.4	.007	....
5106...	19 53.5	+60 37	7.3	M1	.012	+ 0.3	.004	....
5118...	19 55.4	+19 17	3.7	M0	.062	− 0.2	.017	.010
5125...	19 56.7	+17 19	5.6	M4	.015	− 0.4	.006	....
5129...	19 58.0	−27 55	4.6	M4	.037	0.0	.012	....
5149...	20 0.7	+64 37	5.4	M1	.015	0.0	.008	....
5154...	20 1.8	+76 16	6.4	M3	.059	+ 0.2	.006	....
B.D.+36°3883...	20 4.7	+36 21	7.4	M2	......	− 0.5	.003	− .003
B.D.+76° 785...	20 13.1	+77 0	9.3	M0	.495	+ 8.6	.072	.059
5234...	20 19.8	+68 38	6.0	M5	.042	0.0	.006	....
5231...	20 20.1	+40 47	6.1	M0	.054	− 0.5	.005	....
5248...	20 25.1	−22 39	6.2	M1	.029	− 0.1	.005	....
5271...	20 29.0	+48 58	5.6	M2	.037	+ 0.6	.010	....
Cin. 2676...	20 35.8	+ 4 42	8.4	M0	.844	+ 7.9	.079	.063
5306...	20 35.8	−18 24	5.3	M2	.035	− 0.3	.008	....
5338...	20 43.8	− 5 18	4.6	M3	.039	0.0	.012	....
5363...	20 47.3	−27 12	4.2	M1	.017	− 0.3	.013	....
B.D.+61°2068...	20 51.8	+61 53	8.6	M3	.77	+ 9.2	.132	.141
5409...	20 57.0	+19 2	6.0	M3	.075	+ 0.3	.007	.006
Furuhjelm 54...	20 57.1	+39 47	9.7	M3e	.671	+10.1	.120	.081
5430...	21 2.7	−25 18	4.6	M0	0.059	0.0	.012	....
5434...	21 3.6	+38 22	6.3	M0	5.157	+ 8.4	.263	.300
5458...	21 10.9	+59 47	7.1	M2	0.012	− 1.6	.002	....
5457...	21 11.6	−15 29	5.5	M3	.019	0.0	.008	....
5462...	21 12.3	− 9 32	6.8	M4	0.012	0.0	.004	....
Cin. 2757...	21 13.0	−39 9	6.6	M1	3.532	+ 8.4	.229	0.253
5479...	21 17.4	+ 7 2	6.0	M3	0.044	0.0	0.006	....

TABLE I—*Continued*

Name	α 1925	δ 1925	m	Sp.	μ	M	Spec. π	Trig. π
5487...	21ʰ18ᵐ.7	−22° 59′	5.7	M0	0″.041	− 0.3	0″.006	....
5490...	21 18.9	− 9 38	6.2	M0	.050	0.0	.006	....
5522...	21 26.6	+23 19	4.8	M1	.017	0.0	.011	0″.010
5567...	21 37.3	+42 56	5.4	M1	.054	+ 0.4	.010	....
5572...	21 38.5	+ 5 20	5.6	M2	.022	− 0.3	.007	....
5583...	21 40.1	+40 49	5.5	M2	.026	+ 0.1	.008	....
5593...	21 41.2	+58 26	4.4	M2	.002	− 3.0	.003	.011
5595...	21 42.3	− 9 37	6.2	M3	.016	− 0.2	.005	....
5614...	21 45.2	+60 21	5.6	M1	.006	+ 0.5	.010	.020
5647...	21 53.1	+79 12	6.8	M2	.029	− 0.3	.004	....
5650...	21 54.5	+63 16	5.4	M2e	.012	− 2.0	.003	....
5645...	21 54.6	−21 33	6.2	M4	.015	− 0.2	.005	....
5678...	22 1.6	+62 45	5.5	M5	.052	+ 0.1	.008	....
5686...	22 3.0	+44 39	5.3	M0	.017	+ 0.1	.009	.004
B.D.+14°4772...	22 15.7	+15 10	7.2	M1	......	0.0	.004	....
Cin. 2922...	22 25.4	+57 19	9.2	M3	.870	+10.4	.174	.257
5797...	22 25.4	+ 8 45	5.8	M0	.062	− 0.1	.007	....
5804...	22 26.4	+47 19	4.6	M0	0.021	− 2.1	.005	.005
B.D.+52°3240...	22 29.6	+53 21	9.5	M5	......	− 0.2	.001	....
B.D.+53°2911...	22 29.7	+53 25	9.5	M1	1.482	+ 8.6	.066	.030
5820...	22 30.8	+ 0 13	7.0	M1	0.089	− 0.1	.004	....
5843...	22 35.7	+56 24	5.5	M4	.056	− 0.3	.007	....
5855...	22 38.2	−29 45	6.4	M5	.030	− 0.1	.005	....
B.D.+43°4305...	22 43.6	+43 56	9.5	M5e	.86	+11.4	.240	....
5884...	22 45.6	−13 59	4.2	M0	.039	− 0.4	.012	....
5897...	22 48.6	+42 55	5.2	M0	.106	+ 0.2	.010	....
5895...	22 48.7	− 7 59	3.8	M2	.036	− 0.1	.017	....
Cin. 3001...	22 56.3	−22 55	7.6	M1	.899	+ 8.8	.174	....
5934...	22 58.7	− 6 59	6.5	M2	.039	0.0	.005	....
5940...	23 0.1	+27 41	2.6	M2	0.234	− 0.4	.025	.016
Cin. 3014...	23 0.8	−36 18	7.4	M2	6.900	+ 9.4	.251	.292
5952...	23 3.2	+ 9 0	4.7	M2	0.016	+ 0.6	.015	− .003
5962...	23 5.7	+ 8 16	5.4	M4	.004	− 0.9	.005	....
5978...	23 10.4	− 6 27	4.4	M2	.193	+ 0.6	.017	.005
5986...	23 13.0	− 8 8	5.1	M5	.022	0.0	.010	....
5993...	23 14.3	+48 36	5.0	M2	.038	0.0	.010	....
6003...	23 16.3	+41 40	6.0	M0	.044	+ 0.4	.008	....
6006...	23 17.2	+30 0	5.8	M0	.102	+ 0.4	.008	....
6025...	23 21.5	+61 52	5.2	M2	.014	− 0.7	.007	....
6058...	23 29.7	+22 5	5.5	M5	.036	0.0	.008	....
6089...	23 39.6	+ 9 55	5.4	M2	0.007	0.0	.008	....
Lal. 46650...	23 45.3	+ 2 0	8.7	M2	1.393	+ 9.1	.120	.171
6121...	23 47.5	+ 8 54	6.1	M2	0.063	− 0.1	.006	....
6125...	23 48.6	+21 15	6.3	M2	.055	+ 0.5	.007	....
6127...	23 48.7	+18 42	5.2	M3	.047	0.0	.009	0.014
6137...	23 50.9	− 0 17	6.0	M5	.057	− 0.5	.005	....
6143...	23 52.3	−22 24	7.4	M2	.050	0.0	.003	....
6150...	23 53.9	+24 43	4.8	M3	.056	− 0.1	.010	....
B.D.+45°4378...	23 54.8	+46 19	9.2	M0	.64	+ 9.2	.100	....
6171...	23 58.1	− 6 26	4.7	M3	0.053	− 0.5	0.009	....

An examination of the absolute magnitudes of the giant stars listed in Table I shows that the mean value is about -0.2, with some of the brightest stars ranging nearly to -4.5. The faintest of the giant M stars of early type is $+0.7$, and the brightest of the dwarf stars $+7.0$, thus leaving an interval of 6.3 mag. within which no stars are found. For stars of class M5 or later this interval increases

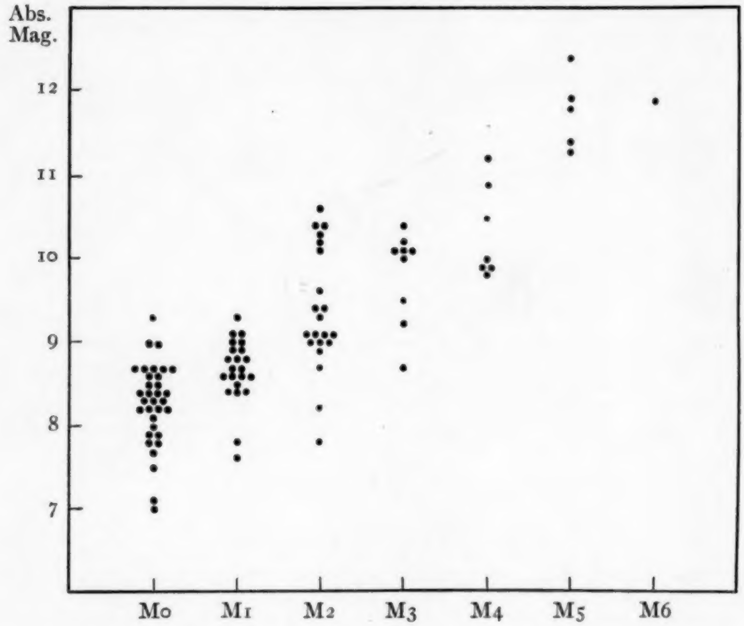


FIG. 1.—Absolute magnitudes and spectral types of dwarf M stars

to 11.0 mag. The mean absolute magnitude of the long-period variables as determined by Merrill and Strömberg is in good agreement with our values for the M stars of advanced type.

The giant stars show little variation in mean absolute magnitude with spectral type, while the dwarfs decrease rapidly in luminosity as the type becomes more advanced. This characteristic of dwarf M stars has been noted by us previously, and reference has been made to the possibility it affords of deriving the parallaxes of faint stars of this type from spectrograms of very low dispersion. A diagram showing the absolute magnitudes of the dwarf stars of Table I

plotted against spectral type is given in Figure 1. The corresponding mean curve is given in Figure 2. It seems clear that in the case of dwarf stars of the more advanced types, at least, a very fair approximation to the parallaxes may be derived from the estimation of spectral type and the assumption of a constant absolute magnitude for each type. Among the dwarf stars smaller dimensions appear to accompany lower temperatures and to lead to decreased luminosity,

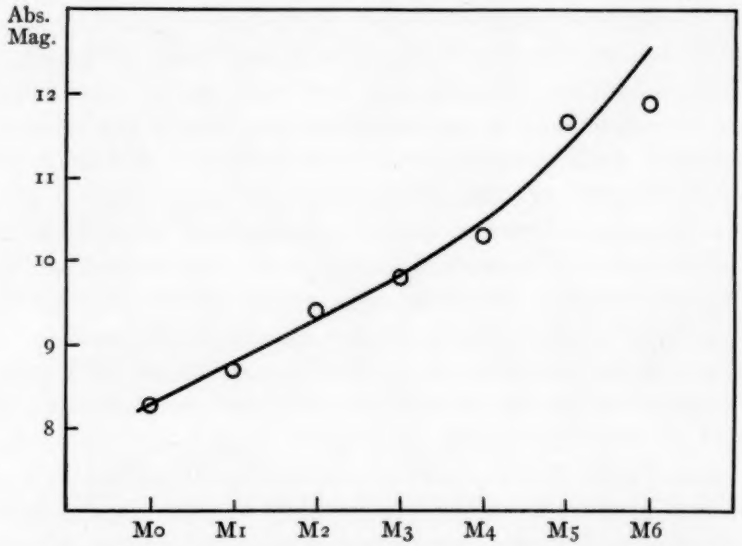


FIG. 2.—Normal points and plot of absolute magnitudes and spectral types of dwarf M stars.

while among the giants the reduction in temperature is compensated by increase in size.

Twenty-eight stars in the list have absolute magnitudes brighter than -1.0, and may for convenience be called "super-giants." Among them are α Orionis, α Scorpii, α Herculis, and several red variables in the h and χ cluster in Perseus. These intrinsically bright stars show a pronounced angular galactic concentration in conformity with the behavior of the brightest stars of other spectral types, although, as is well known, the M-type giants in general show no such effect. The average galactic latitude of these twenty-eight stars is 7°, only five stars having values above 10°.

Three of the super-giants belong to the W Cephei type of variable, and have spectra which show bright lines of hydrogen, as well as certain unidentified emission lines. Seven stars, of which four are irregular variables, are shown by their radial velocities to be members of the double cluster in Perseus. A parallax of between $0\rlap{.}''001$ and $0\rlap{.}''002$ is indicated by these stars. It is of interest to note that the mean proper motion of the seventeen super-giants for which values are known is only $0\rlap{.}''017$, a value considerably smaller than that for the ordinary giants.

An outstanding feature of the absolute magnitudes of the giant stars other than the super-giants is their small dispersion. If this were due to any failure on the part of the spectral criteria to show differences of absolute magnitude among these stars, it would certainly be expected to show for the brightest stars as well. The spectral differences, however, between the ordinary giants and the super-giants are well marked. A comparison of the mean absolute magnitudes of groups of stars of different reduced proper motion H $(m+5\log\mu)$ shows a fairly regular though small increase in luminosity with decrease in H. A similar comparison of H with mean absolute magnitude derived from trigonometric parallaxes, of which about fifty are available, gives quite comparable results, and shows that trigonometric parallaxes also indicate small dispersion in absolute magnitude among the ordinary M-type giants. Since the reduced proper motion H is a simple function of absolute magnitude and linear cross-motion, it is evident that the observed dispersion in H, which is not very large, may be accounted for by a considerable dispersion in linear cross-motion and little dispersion in absolute magnitude. The large dispersion in radial velocity observed among the normal M-type giants, larger than for any other class of giant stars, would indicate a similar dispersion in linear cross-motion and would be in excellent agreement with this view of a small range in absolute magnitude.

There are seventy-one giant stars in the list for which trigonometric parallaxes have been measured. Of these, sixty-seven are found in Schlesinger's *Catalogue of Parallaxes* and have been corrected for systematic errors on the basis of the system derived by him. The direct comparison of the spectroscopic and trigonometric paral-

laxes of these stars shows an excellent degree of agreement, the mean difference being less than $0\overset{''}{.}001$, and the average deviation between $0\overset{''}{.}008$ and $0\overset{''}{.}009$. Since the reduction tables from which the spectroscopic absolute magnitudes and parallaxes are calculated were based on results derived from peculiar motions without any use of trigonometric parallaxes, this agreement affords important evidence for the accuracy of the system employed.

In the case of the dwarf stars the trigonometric parallaxes have been used exclusively in the derivation of the reduction curves, and close agreement of the mean results is to be expected. A comparison of sixty-four stars shows a systematic difference of about $0\overset{''}{.}002$, the trigonometric parallaxes being the larger. This would correspond to considerably less than 0.1 in absolute magnitude.

Several stars among the dwarfs for which no trigonometric parallaxes have been measured are found to have values of $0\overset{''}{.}1$ or larger. These are Cin. 251, Cin. 456, B.D.$+63^\circ 869$, Cin. 1633, βG.C. 6710 N, B.D.$-7^\circ 4003$, B.D.$-12^\circ 4523$, Wolf 636, B.D.$+45^\circ 2505$, B.D. $+43^\circ 4305$, Cin. 3001, and B.D.$+45^\circ 4378$. If the spectroscopic parallaxes of B.D.$-7^\circ 4003$ and B.D.$-12^\circ 4523$ are confirmed by observers of trigonometric parallax they will be among the nearest known stars.

There are 155 giant stars in Table I which were included in the list of 1646 stars for which absolute magnitudes were published by us in 1921.[1] The present values are 0.4 mag. brighter on the average, a result which is quite satisfactory in view of the low weight of the earlier determinations. A similar comparison has been made for eighty-six giant stars common to our list and that of Young and Harper.[2] The Mount Wilson values are, on the average, nearly 0.8 mag. fainter than the Victoria results. The agreement is much better for the early than for the later subdivisions of type, the differences becoming progressively greater and amounting to as much as 1.5 mag. for the relatively few stars of classes M5 and M6. The explanation is probably to be found in the variation with spectral type of the intensities of the lines used for determinations of absolute magnitude.

[1] *Mt. Wilson Contr.*, No. 199; *Astrophysical Journal*, **53**, 13, 1921.

[2] *Publications of the Dominion Astrophysical Observatory*, **3**, No. 1, 1924.

A result similar to that obtained from a comparison with the Victoria values is found for the absolute magnitudes published by Rimmer.[1] The Mount Wilson values are slightly less than 0.7 mag. fainter for forty-seven stars observed in common. For stars of classes M0 and M1 the difference is 0.2 mag., but for the more advanced types the average difference is nearly a magnitude.

The present investigation has given no evidence of the existence of stars intermediate in absolute magnitude between the giants and the dwarfs, or of spectral types intermediate between these radically different spectra. In the case of dwarf stars which are observed because of their large proper motions, the effect of selection must necessarily be present, and if dwarf stars somewhat brighter than 7.0 in absolute magnitude exist, they may not have been detected because they are not included on our observing lists. For the giant stars, however, no effect of selection according to proper motion is present. If we may assume that the M stars given in Boss's *Catalogue* are complete to apparent magnitude 6.5, we find accordingly that no star of absolute magnitude 3.0 can be present within a distance from the sun defined by a parallax of $0\overset{''}{.}020$, and no star of absolute magnitude 2.0 within a distance defined by a parallax of $0\overset{''}{.}013$. The results for a considerable number of stars of fainter apparent magnitude, observed mainly in the Selected Areas, add strength to this conclusion, and make the existence in appreciable numbers of stars of intermediate absolute magnitude or spectral type exceedingly improbable.

MOUNT WILSON OBSERVATORY
August 1926

[1] *Memoirs of the Royal Astronomical Society*, **64**, Part 1, 1925.

PHOTOGRAPHS OF MARS, 1926

By FRANK E. ROSS

ABSTRACT

Photographs of *Mars* were made at Mount Wilson with the 60-inch reflector, in light of *five different colors*. The *surface markings* are portrayed by the *longer wave-lengths*, while the *atmospheric clouds and haze* are well brought out in the *shorter wave-lengths*. A cloud formation of unusual brilliance was photographed. The *atmospheric rim-light* is a feature of the *ultra-violet* pictures. The *excess* of *diameter* of Mars in the *ultra-violet* over the diameter in the infra-red, discovered by Wright, *is confirmed*.

During a visit to the Mount Wilson and Lick observatories, in September and October of the present year, the writer secured several hundred photographs of Mars, using an enlarging camera of special design attached to the 60-inch telescope at Mount Wilson, and to the 36-inch refractor at the Lick. With the Mount Wilson 60-inch mirror, at the Cassegrain 80-foot focus, photographs were made in five colors, namely, ultra-violet, blue, yellow, red, and infra-red. The enlargement was 4.0-fold, making the equivalent focal length 320 feet. With the Lick refractor, only yellow and infra-red photographs were attempted. On account of the pressure of other work, considerable time must elapse before these photographs can be adequately studied. It is accordingly thought best to publish immediately one complete color series. The ones selected are from a series obtained at Mount Wilson on the morning of October 16, the conditions then being more favorable than on any other night on which photographs were secured. A further reason for selecting this particular series is the interesting and unusual phenomena taking place, apparently in the atmosphere of Mars, at this time.

A few brief details of camera and plates will now be given. The enlarging camera was made in the shop of the Yerkes Observatory by C. Ridell. A special feature of the camera is a device for guiding on the planet itself while the exposures are being made. This is secured by inserting in the beam of light a thin piece of optically worked, unsilvered glass, inclined at an angle of 45° to the axis, which reflects some of the light of the planet to a guiding eye-piece

set at right angles to the telescope. Two images are, of course, formed, due to reflection from front and back surfaces, but this is not a serious matter. Not the least of the advantages of this device is the ability to watch for the moments of best seeing, exposures being made only when the planet is quiescent. A negative enlarging lens, of approximately 6 inches focal length, was generally used. A specially designed tube-sensitometer impressed standard squares on each plate, so that relative light-intensities can be calculated.

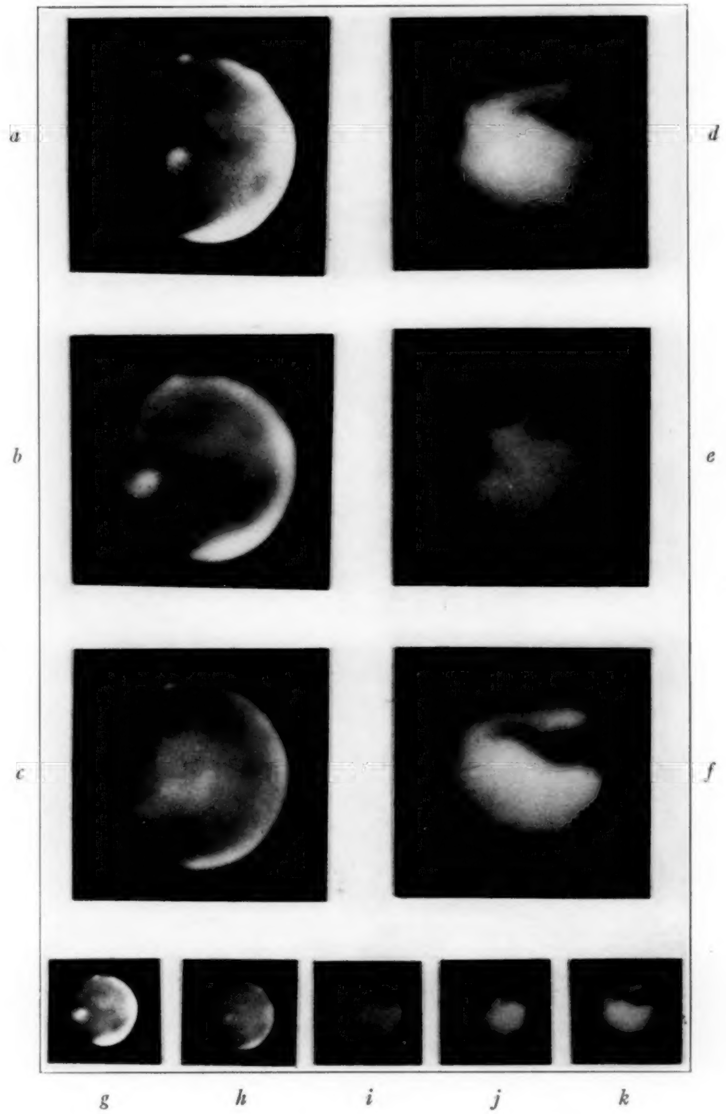
The filters were usually placed about 1 inch in front of the plate. They were rotated through 90° after each exposure. In general, seven exposures were made on each plate, 2×5 inches in size. The ultra-violet exposures were made on "Eastman 33" plates in conjunction with Wratten filter No. 18, transmitting from 3600 to 4050 A. The same plate was used for the blue pictures, without filter. Eastman erythrosin-stained process plates were used for the yellow, and Ilford process panchromatic, for the exposures in the red. Eastman kryptocyanin plates, with a red filter, the maximum sensitivity being at 7600 A, were used for the infra-red. The exposure-times for the ultra-violet and infra-red averaged about 3 minutes, for the yellow and red about 10 seconds, and the blue, about 2 seconds.

Plate VIII accompanying this article contains a series of enlarged images, as well as a set of unenlarged prints from the original negatives. In preparing the enlargements, contact positives were first made on kryptocyanin plates, using infra-red light. This was found to be especially advantageous in bringing out the faint atmospheric and surface detail in the blue and ultra-violet negatives. In the case of the small-size prints shown on the plate, for the blue and ultra-violet, second negatives were made by copying twice on the kryptocyanin plates, considerably enhancing the contrast.

The original negatives were exposed as follows (Universal Time) on October 16, 1926:

a,	9^h15^m	*g*,	10^h25^m
b,	10 35	*h*,	9 29
c,	7 54	*i*,	9 1
d,	9 1	*j*,	7 29
e,	7 29	*k*,	9 58
f,	9 58		

PLATE VIII



MARS, PHOTOGRAPHED IN LIGHT OF DIFFERENT WAVE-LENGTHS WITH 60-INCH MOUNT WILSON REFLECTOR, ON OCTOBER 16, 1926

a, *b*, *g*, ultra-violet; *c*, *h*, blue; *d*, *i*, yellow; *e*, *j*, red; *f*, *k*, infra-red; *g*–*k* are of original size.

NOTES ON THE PHOTOGRAPHS

The dark tongue on the left of the disk of the planet is the Mare Sirenum. Above is the Sinus Aonius, and to the right the Solis Lacus is prominent. The most remarkable feature of the photographs is the large bright cloud just below the Solis Lacus and quite close to the equator. It is very prominent in the ultra-violet pictures, less so in the blue, and barely discernible in the yellow (Plate VIII, *i*). The same cloud appeared on photographs on the two nights preceding. I have not yet examined them for a possible motion of the cloud in the interval of two days. The term "clouds" is used advisedly, for their properties seem to be different from clouds as we know them. The question arises, Why are they prominent in short waves, in the ultra-violet, and relatively weak in yellow, just the opposite of what we normally expect? The bright ring on the sunrise edge of the planet, so striking in the ultra-violet prints, proves the existence of a strongly scattering atmosphere. Granting an atmosphere then, clouds, such as we know, would be quite invisible in ultra-violet light, and strongly visible in the yellow and red, which is directly opposed to the facts. On the other hand, if we admit only an insignificantly scattering atmosphere, their explanation is not so difficult. It is only necessary to assume a low albedo in the ultra-violet of the surface of Mars—a very reasonable assumption. The faintness of the clouds in the yellow and red can, under these assumptions, be explained by assuming further a lower albedo for them than that of the clouds with which we are familiar, and, moreover, but very little higher than that of the planet's surface, again a reasonable assumption. A further argument against an extensive atmosphere is the difficulty of explaining the high visibility of the polar cap when it nearly vanishes on the edge of the disk, as at the present opposition. I refer to its extreme sharpness of outline under these conditions, seen visually.

In addition to the prominent cloud visible on the ultra-violet prints (*a* and *b*) many other fainter obscuring formations are to be noted. To such an extent are the planetary surface details blotted out on the shorter wave-lengths that the prominent surface feature, the Mare Sirenum, can be seen only with the greatest difficulty in the blue print (*h*) and is entirely invisible in the ultra-violet. It is

evident that we have at hand a powerful tool for the study of conditions above the surface of Mars. Moreover, my experience has shown that good seeing is not necessary to photograph these atmospheric features, on account of their broad extent, as compared with the difficulty of observing the surface details, which have hitherto chiefly interested the student of Mars.

During the opposition of 1924, Wright, at the Lick Observatory, obtained an extensive series of photographs of Mars in the violet and ultra-violet (*Lick Observatory Bulletin*, No. 366, 1925), showing obscuring formations similar to those just noted, which he described as the "impermanent features" on the planet's surface. The extended collection of similar photographs which he is obtaining at the present opposition should, on account of their continuity, prove exceedingly valuable in interpreting the phenomena underlying these interesting "atmospheric" pictures.

VARIATION OF DIAMETER WITH WAVE-LENGTH

The pioneer work of Wright in the color photography of Mars, during the 1924 opposition, disclosed a considerable difference in size between the diameters of the planet as measured on plates exposed, respectively, to ultra-violet and infra-red light, the difference amounting to 3 per cent of the diameter. Various explanations of the difference have been proposed. Approximately contemporaneously with the work of Wright, during the winter of 1924–1925, the present writer, in photographing the moon in infra-red light, with the Yerkes 40-inch refractor, and with the 24-inch reflector, found it exceedingly difficult to obtain any impression of the terminator, near first or last quarter. Additional data were furnished by photographs of Saturn and Jupiter, with the 40-inch refractor, the images in the infra-red being smaller than the images taken in yellow light. Two possible explanations were considered at that time: (1) an edge effect, due to differences in the plate and its behavior with variation in the wave-length of light; (2) chromatic variation in the distribution-curve of reflected light, so that of infra-red light striking a spherical surface at grazing incidence, an unduly small percentage is reflected. Both of these effects, if present, can be tested by laboratory experiment. An extensive investigation was carried out by the

writer at the Yerkes Observatory in April, 1926. Artificial planets were photographed under carefully controlled conditions, a well-corrected apochromatic lens being employed, on plates having varying characteristics, and in all colors from ultra-violet to infra-red. Scale was controlled by artificial stars surrounding the test sphere. As an artificial planet, a round, frosted electric bulb was used. Photographs were made of it while self-luminous, and when illuminated from without. In the latter case Mars at opposition was imitated by placing the source of illumination in front and just below the line of sight, shielded, of course, from the camera. In order to obtain data which would differentiate between the two effects noted above, a third test-object was used, a white, round, flat disk. In order to test the effect of size of image, the distance of the camera was changed. Images 1 mm and 3 mm in diameter, respectively, were studied in this way. Altogether several hundred photographs were obtained, which were carefully measured by Dr. Oliver J. Lee. A few were also measured by the writer as a check. The results were almost entirely negative. A small effect was noted, the kryptocyanin plates giving a smaller image than any of the others tried, by 0.030 mm, the difference being constant for all three test-objects and for the two sizes of image. On panchromatic plates the size of image remained unchanged from blue to red, showing that there is no true color-effect. Since results from all three test-objects agreed, the second of the possible explanations proposed above is definitely ruled out. There remains a small effect under (1), namely, a constant edge-effect, amounting to 0.015 mm for each edge, applicable to the infra-red plates, independent of the size of image. If this were applied to the measures of Wright, it would reduce the effect he found from 3 to 2 per cent, the size of his images of Mars being approximately 3 mm.

The photographs of Mars secured by the writer at the present opposition, both at the Lick Observatory, using the 36-inch refractor, and at Mount Wilson, with the 60-inch reflector, confirm Wright's results. Below are given my measurements of some of the plates secured at Mount Wilson on October 16, care being taken to select for measurement only those images which are considered to be correctly exposed. The polar diameter was measured. As a check,

the same images were measured on positive plates, secured by contact printing. These positives were the same as those used in making the enlargements shown in Plate VIII. By taking the arithmetical mean of the measurement of the positive and negative plates, the systematic error of encroachment of the image, for normal exposures, should be eliminated. The variation in the character of the edge with color, especially in the case of the positive images, was found to be too slight to affect systematically the setting of the thread. Four images were measured in each color. The mean results are as follows:

	Mean Diameter		
	Negative Images mm	Positive Images mm	Mean mm
Infra-red	9.31	9.23	9.27
Red	9.19	9.25	9.22
Yellow	9.41	9.50	9.45
Blue-violet	9.73	9.84	9.78
Ultra-violet	9.80	9.90	9.85

These measures cannot be reduced to arc since the scale was not determined. It will be noticed that the infra-red and red diameters are practically in agreement, and the blue-violet and ultra-violet, and that these two groups stand apart by 6 per cent, or double the amount found by Wright. But it is to be noted that Wright rejected the diameters of the violet images which were exposed on Seed 23 plates,[1] using in the final discussion only those made on Seed lantern plates. It is interesting to note that his measures on Seed 23 in the violet, compared with the infra-red, give a value of 6 per cent for the difference in diameter, in exact agreement with the result found above. My laboratory measurements of diameters on these plates, in the research mentioned above, do not disclose any appreciable difference, so that it is hard to believe that it is purely a plate-effect. As a tentative explanation, it may perhaps be a plate-effect combined with aberrations of the telescope and bad "seeing." A "hard-working" plate, like Seed lantern and kryptocyanin, would not record the outer wanderings of the image, or its outer shadings, whereas a "softer" plate, such as Seed 23, which is identical with the Eastman 33 used above for the violet and ultra-violet, undoubt-

[1] *Lick Observatory Bulletin*, **12**, 54, 1925.

edly would. It is quite clear that the difference found between the size of the atmospheric image, which is certainly the record left on the plate when exposed to light of short wave-length, and the size of the image of the surface itself, impressed on the plate in the longer wave-lengths, is not a measure of the depth of the atmosphere, unless we are sure that the photographic effects are eliminated or accurately balanced. The subject is discussed at length by Wright in the paper quoted above. From the long series of plates secured by the writer, at the present opposition, the effect of variation in conditions of "seeing" on diameter can be judged. I am not convinced of its importance, from the following circumstance. The exposures of the blue-violet plates, of which the measures are given in the foregoing table, were taken under exceptionally fine conditions of seeing. Although the magnification employed in the guiding eyepiece is about 1500, hardly a tremor was noted during the entire series of exposures of this plate. The average exposure-time was 2 seconds. On the other hand, the exposure-time for an ultra-violet image of proper density is about 3 minutes, and yet the diameters in these two colors agree, as will be seen from the foregoing table. There remain the possible effects of atmospheric dispersion and of aberrations of the mirror. Since exposures were made near the zenith, atmospheric dispersion should be negligible. In the direction of diminishing the aberrations, the effect of "stopping down" the mirror should be tried out. It is clear that Wright was entirely justified in rejecting the diameters in the violet on Seed 23 plates.

I am indebted to Dr. W. S. Adams and to Dr. R. G. Aitken for the opportunity of carrying on these researches. I also wish to acknowledge helpful suggestions from W. H. Wright, R. J. Trumpler, F. G. Pease, and from E. C. Slipher of the Lowell Observatory.

Yerkes Observatory
November 8, 1926

THE DWARF COMPANION TO CASTOR AS A SPECTROSCOPIC BINARY AND ECLIPSING VARIABLE[1]

YY Geminorum

By ALFRED H. JOY and R. F. SANFORD

ABSTRACT

Spectrographic observations.—The spectral type of Castor C is dM1e. $H\alpha$, $H\beta$, $H\gamma$, $H\delta$, and H and K of calcium are present as emission lines. In 1916, the star was found to be a spectroscopic binary, both bright and dark lines being double, and both spectra being nearly alike, except that one was somewhat stronger than the other. The period was found to be 0.814266 day, with no indication of eccentricity. Thirty-five spectrograms have been obtained as listed in Table I. Spectrographic elements were determined and corrected by a least-squares solution: $e=0.0$ (assumed); $\gamma=+4.3$ km/sec. $K_1=114.0$ km/sec.; $K_2=126.7$ km/sec. A comparison of the orbits of the system of Castor is given in Table III.

The *intensities of the two absorption spectra* are in the ratio of 5:4. The *emission lines* seem to be *stronger when on the side of greater wave-length.* They give the same velocities as the absorption lines. The *spectroscopic absolute magnitude* of the brighter component is estimated from plates showing single lines to be 9.2, which corresponds to a *parallax* of 0."083.

Absolute dimensions.—With the aid of van Gent's light-curve, *photometric elements* and *absolute dimensions* have been computed: $a_0=0.88$; $k=0.89$; $i=86.^\circ4$; $a_1+a_2=$ 2,700,000 km; $r_1=0.76\ \odot$; $r_2=0.68\ \odot$; $m_1=0.63\ \odot$; $m_2=0.57\ \odot$; $\rho_1=1.4\ \odot$; $\rho_2=1.8\ \odot$. The surface brightness of both stars is 3.6 mag. fainter than that of the sun.

Star C of the system of Castor is distant 73″ in position angle 165°, and is known to have the same proper motion (0."207 in 248°) and parallax as Castor. The apparent magnitude being 9.0, it must have an exceedingly low intrinsic luminosity.

The first slit spectrogram was made on March 15, 1916, and revealed the presence of two closely similar spectra showing absorption and emission lines whose characteristics are discussed in detail in another section of this paper. This first plate showed a large difference in wave-length between the two sets of lines, which, interpreted as a Doppler shift, indicated large orbital velocity. Subsequent observations gave spectra which confirmed this interpretation. The stellar magnitude of C is such that most of the spectrograms were necessarily made with a one-prism spectrograph equipped with a short camera giving a dispersion of 75 A per millimeter at $H\gamma$. The difficulties caused by the superposition of two

[1] *Contributions from the Mount Wilson Observatory,* No. 320.

spectra are therefore enhanced by the small dispersion, which makes for relatively low accuracy in the determination of the radial velocity. As far as can be judged from our measures, there seem to be no grounds for treating the velocities from the emission lines differently from those depending upon the absorption lines.

Observation of the separations of the lines of the two spectra upon successive nights for a considerable time gave the impression that the changes took place in a period slightly over four days, with, however, some disquieting inconsistencies. Pairs of plates from the same night were then made to test for a shorter period, with the result that on the second attempt the two plates, C 3718 and C 3721, whose mid-exposure times differ only 0.211 day, showed a totally different arrangement of the lines of the two component spectra. In the first case, the lines were single; and in the second, double, the indicated difference of velocity being about 230 km/sec. Evidently a period much shorter than four days had to be looked for, unless the velocity changes departed greatly from a sine curve.

Thirty-five spectrograms of a varied but still usable quality have been made as listed in Table I. Plates on which the lines of the two components are blended give, of course, but one velocity. Such velocities are entered in the column for the primary, but should be understood to be measures of plates whose lines could not be resolved. Except the first three plates, which were obtained with the 60-inch reflector, all exposures have been made with the 100-inch reflector.

The assumption that the velocity variation takes place in somewhat less than a day resulted in a satisfactory grouping of the observations about a single epoch with a period equal to 0.814266 day. More than forty-five hundred revolutions of the stars in their orbits are covered by the observations. Those velocities which are critical for a test of the correctness of the period can hardly admit of a shift of 0.05 day, which sets the upper limit of inaccuracy in the period at about 0.00001 day.

The freehand curve drawn through the observations plotted to one epoch indicated that the orbits might be assumed to be circular. Elements have been derived by a graphical method. The epoch from which the phases have been reckoned is the time of zero ve-

locity of the components when the more massive star is passing from recession to approach.

TABLE I

OBSERVATIONS OF THE COMPANION TO CASTOR

Plate No.	Date	G.M.T.	Phase	Velocity		O−C	
				Prim.	Sec.	Prim.	Sec.
				km/sec.	km/sec.	km/sec.	km/sec.
γ 4678....	1916 Mar. 15	16^h55^m	$0^d.583$	+100	−130	−18	−10
4683....	Mar. 16	17 59	.812	+ 29	....	....	....
4745....	Apr. 16	16 07	.794	+ 16	....	....	....
C 249....	1920 Jan. 14	23 04	.304	− 70	+ 82	+ 8	−13
262....	Jan. 29	22 03	.602	+120	−111	+ 2	+12
270....	Feb. 4	18 57	.773	+ 3	....	....	....
309....	Mar. 6	16 30	.730	+ 58	− 68	−14	+ 4
326....	Mar. 11	19 50	.169	−118	+124	−12	− 2
330....	Mar. 12	18 36	.303	− 69	+ 85	+10	−11
377....	Apr. 11	17 32	.130	− 91	+123	+ 1	+12
1634....	1922 Mar. 21	20 00	.008	+ 7	....	....	....
1638....	Mar. 22	18 12	.119	−103	+ 86	−18	−18
2490....	1923 Oct. 21	0 48	.079	− 57	+ 98	+ 5	+21
2543....	Nov. 21	19 38	.108	− 59	+116	+21	+18
2552....	Nov. 23	0 25	.493	− 6	....	....	....
2556....	Nov. 24	0 20	.678	+124	−103	+21	+ 2
2560....	Nov. 26	1 03	.263	−109	+130	− 2	+12
2578....	Dec. 17	0 23	.064	+ 16	....	....	....
2683....	1924 Feb. 16	20 07	.002	− 2	....	....	....
3122....	1925 Jan. 9	20 25	.680	+110	−113	+ 8	− 8
3126....	Jan. 10	20 30	.054	+ 6	....	....	....
3129....	Jan. 11	20 14	.231	−112	+137	− 5	+ 9
3142....	Jan. 13	20 14	.601	+124	−118	+ 6	+ 5
3145....	Jan. 31	19 05	.639	+123	−115	+ 9	+ 5
3153....	Feb. 2	21 25	.293	− 83	+ 97	+ 1	− 5
3202....	Mar. 12	17 43	.683	+ 95	−108	− 6	− 7
3289....	May 7	16 05	.437	+ 17	....	....	....
3666....	1926 Jan. 24	17 00	.275	−107	+112	−13	0
3669....	Jan. 24	23 05	.532	+ 82	− 84	−14	+16
3718....	Feb. 27	15 25	.010	+ 6	....	....	....
3721....	Feb. 27	20 28	.221	−104	+129	+ 5	− 1
3725....	Feb. 28	16 20	.235	−113	+115	− 7	−13
3733....	Mar. 24	18 53	.716	+ 78	−99	− 3	−17
3738....	Mar. 29	17 53	.799	+ 1	....	....	....
3772....	Apr. 26	16 18	0.232	− 91	+132	+16	+ 4

Only results from plates giving the velocities of both components have been used to correct these preliminary elements. Twelve normal places were determined for each component, and with these a set of normal equations was formed in the manner described by Harper.[1] In spite of very considerable disparity in quality, all individual velocities have been treated as of equal weight.

[1] *Publications of the Dominion Observatory*, 1, 327, 1914.

The preliminary elements, the corrections, and the adopted elements are given in Table II. The value of [*pvv*] for the normal places is 12 per cent less for the adopted elements than for the preliminary elements.

According to H. D. Curtis,[1] the velocities of the systems α^1 and α^2 Geminorum are -0.98 and $+6.20$ km/sec., respectively. The same element for star C is $+4.3$ km/sec. We thus have similar proper motions, parallaxes, and radial velocities, indicative of the close relationship between stars A, B, and C. The function $(a_1+a_2)\sin i$, the projected distance of the centers of the two components, is so

TABLE II

ELEMENTS OF THE COMPANION OF CASTOR

	Preliminary Elements	Corrections	Adopted Elements	
P	....	....	0.814266 day	
K_1	117	-3.0	114.0	km/sec.
K_2	130	-3.3	126.7	km/sec.
T	2423746.520	$+0.004$	3746.524	
γ	$+6$	-1.7	$+4.3$	km/sec.
$(a_1+a_2)\sin i$	....	....	2,695,200	km
$m_1\sin^3 i$	....	....	0.63 ⊙	
$m_2\sin^3 i$	....	....	0.57 ⊙	

small that even for rather dense stars the conditions are favorable for eclipses, whose epochs should correspond to the times when the spectral lines are superposed.

Figure 1, where abscissae are phases and ordinates, velocities, shows the computed velocity curves. The velocities as measured upon the individual plates are plotted as circles. The column headed O−C in Table I gives the differences between the observed velocities and this curve. The representation, although ragged, is about what may be expected from such spectra obtained with comparatively low dispersion.

It may be of interest to recall the various orbits involved in this system. The visual orbit of α^1 about α^2, according to Burnham, is as yet quite indeterminate. It is certain, however, that its period is a matter of centuries, various computers deriving from 232 to

[1] *Lick Observatory Bulletins*, 4, 55, 1906.

1000 years for this element. Each of the three stars is a spectrographic binary, but C is the only one that reveals the spectra of both components. A comparison of some of the characteristics of the stars and their orbits is given in Table III. The projected distance from AB to C is 1.43×10^{10} km ($\pi = 0\overset{''}{.}076$), or 960 astronomical units. It is interesting to find that $a \sin i$ for the primary members of the spectrographic binaries α^1 and α^2 is so closely the same as for the two components of star C.

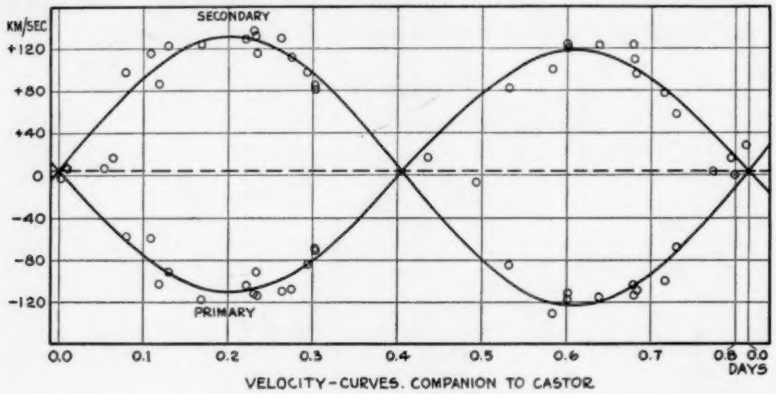
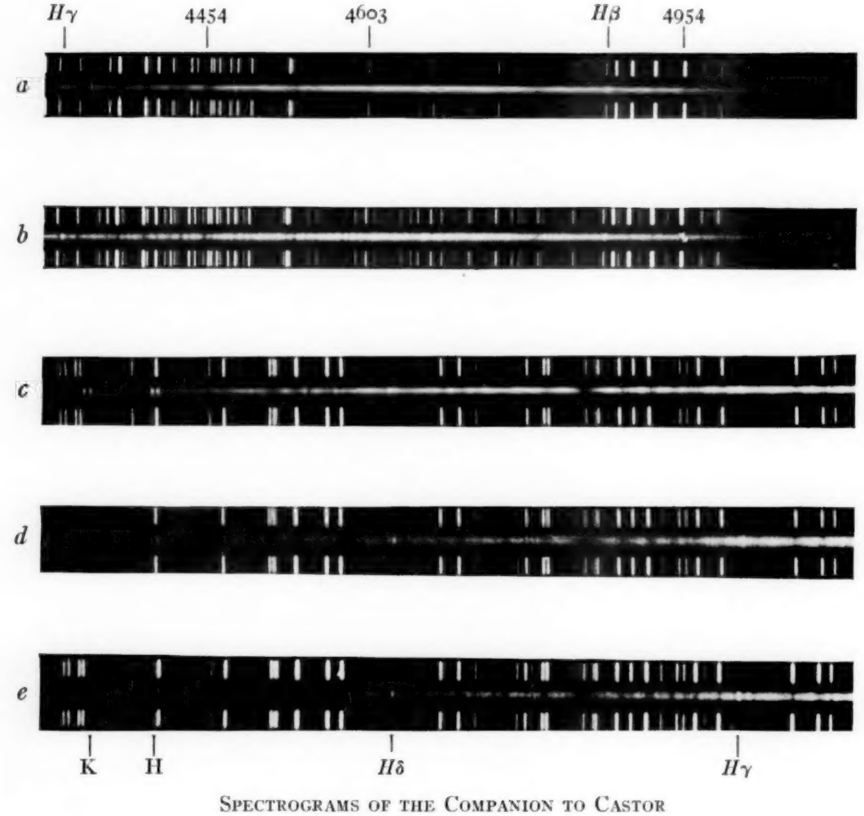


FIG. 1

THE SPECTRUM

The spectra of the components of the companion C are unusual and interesting. Both spectra show on all plates taken when the separation between the components is sufficient. The spectral type is dM1e with no certain difference in type between the components. The absorption spectrum pertaining to the more massive component is somewhat stronger than that of the less massive component, approximately, in the ratio of 5:4. The stars belong to the small group of M-type dwarfs which show H and K and the Balmer series of hydrogen as emission lines. Bright $H\alpha$ is present on one plate which shows the red portion of the spectrum. The hydrogen lines fall off in intensity from red to violet. No member of the series of wave-length shorter than $H\delta$ has been seen. H and K of ionized calcium are strong and sharp. All the bright lines give the same velocities as the absorption lines of the corresponding spectrum.

PLATE IX



SPECTROGRAMS OF THE COMPANION TO CASTOR

a) C262, double lines
b) C270, single lines
c) C3142, double lines, more massive component displaced to the violet
d) C3145, double lines, more massive component displaced to the red
e) C3718, single lines

They double and become single with the absorption lines as illustrated in Plate IX.

The relative intensity of the emission lines of the two components varies in a marked degree. When they are on the red side, the lines of the more massive component are about twice as strong as those of the lesser component. When their positions are reversed, at the opposite phase, and the lines of the massive component are on the violet side, they no longer maintain their ascendency. They are, in fact, some 20 per cent weaker in the mean than the lines of the

TABLE III

COMPARISON OF ORBITS OF CASTOR

	AB (visual)	A(a^2)	B(a^1)	C
Spectrum	....	A3s	A8s	dM1e
m	....	2.0	2.8	9.6, 9.8
M ($\pi=0''.076$)	....	1.4	2.2	9.2, 9.4
P	232–1000 years	9.2 days	2.9 days	0.8 day
e	0.4	0.5	0.0	0.0
K	....	13.6km/sec.	31.8km/sec	114.0km/sec. 126.7km/sec.
γ	....	+6.2km/sec.	−1.0km/sec.	+4.3km/sec.
$a \sin i$	$a=$ 1,141,000,000km 76.4 ast. u.	1,485,000 km	1,279,000 km	1,276,000 km 1,419,000 km

other component. In other words, when the velocities are such as to separate the lines, the red member of the pair is, with one or two exceptions, the stronger. A bright line originating from a given component is relatively enhanced when it is on the red side, that is, when the star is receding from us. The cause of this peculiar phenomenon is not clear. There seems to be nothing in the structure of the lines themselves as observed with low dispersion to suggest an explanation. The effect is the same for all the bright lines observed. The absorption lines behave normally. It is possible that the effect of the rapid orbital motion in a resisting medium might be such as to cause the higher atmosphere which produces the emission to be dragged behind. Thus, the receding star would show strengthened bright lines.

ABSOLUTE MAGNITUDE

The spectrographic absolute magnitude has been determined by the use of the dwarf curves for six lines. Eleven plates showing single

lines are available for this purpose. The resulting absolute magnitude, which probably should be ascribed to the brighter star, is +9.2. The combined apparent magnitude is 9.0, which gives 9.6 and 9.8 for the separate components provided that one is 25 per cent brighter than the other. The parallax is, accordingly, 0".083. The value, 0".076, given in Schlesinger's catalogue as a mean of the trigonometric determinations for the different members of the system, would correspond to an absolute magnitude of 9.0 for the brighter component.

THE PHOTOMETRIC ORBIT AND ABSOLUTE DIMENSIONS

After the preceding portions of this paper had been written and arranged for publication, the *Bulletin of the Astronomical Institutes of the Netherlands*, No. 97, came to hand. It contains an important communication by H. van Gent entitled "The Distant Companion C of Castor as an Eclipsing Variable Dwarf Star of Determinable Surface Brightness." Van Gent finds from photographic observations that the companion to Castor is an eclipsing variable[2] with equal minima. The period of the spectrographic orbit is confirmed. He makes use of a preliminary announcement[1] of early spectrographic observations to determine the absolute dimensions and other interesting physical conditions of the system. These results may be somewhat revised by applying the more complete data of the present paper.

The light-curve is not sufficiently well determined to admit of definitive elements from the photometric observations. It seems clear, however, that the minima are approximately equal and that the maxima show no effect of ellipticity, such as appears when the stars are elongated in the direction of the line joining their centers.

For uniformly illuminated disks with equal minima, the surface brightness must be the same for the two stars. The spectrographic observations confirm this conclusion.

According to van Gent, the loss of light at the minima is 0.538 mag., or 0.391 in intensity. From the strength of their spectral lines,

[1] Adams and Joy, *Publications of the Astronomical Society of the Pacific*, **32**, 158, 1920.

[2] YY Geminorum, see *Astronomische Nachrichten*, **228**, 353, 1926.

we estimate the light of the two stars to be in the ratio of 4:5. Then, for the same surface brightness, the radius of the smaller in terms of the larger, or k in Russell's notation, is 0.89.

From

$$a_0 = 1 - \lambda_1 + \frac{1 - \lambda_2}{k^2} ,$$

the fraction of obscuration is found to be 0.88. The light-curve indicates the duration of eclipse to be 0.12 of the period.

With the aid of Russell's Table I, r_1 and i may now be found from the equations,

$$\cos^2 i \cos^2 \theta' + \sin \theta' = r_1^2 (1+k)^2$$
$$\cos^2 i = r_1^2 (1+kp)^2 .$$

Thus,

$$i = 86\overset{\circ}{.}4 , \qquad r_1 = 0.197 , \qquad r_2 = 0.175$$

A solution involving darkening at the limb gives values which are not essentially different from these results. In view of the large uncertainties of the light-curve, it seems hardly necessary to include them here.

Combining the photometric and spectrographic elements, we have the absolute dimensions:

$a_1 + a_2$	= 2,700,000 km = 0.018 ast. u.
r_1	530,000 km = 0.76 ☉
r_2	472,000 km = 0.68 ☉
m_1	0.63 ☉
m_2	0.57 ☉
ρ_1	1.4 ☉
ρ_2	1.8 ☉

The surface brightness is 3.6 mag. fainter than that of the sun.

The interest attaching to a more exact knowledge of the dimensions and physical conditions of these dwarf stars would make a more complete photometric study well worth while.

MOUNT WILSON OBSERVATORY
August 1926

A GRAPHICAL REDUCTION OF RADIAL VELOCITIES TO THE SUN

By G. VAN BIESBROECK

ABSTRACT

The reduction of radial velocities to the sun can be expressed simply as function of A, the right-ascension of the point in the sky toward which the earth's motion around the sun is directed. A can in turn be tabulated as a function of the calendar date. The multiplications involved are done by a thread stretched over a diagram drawn once for all. The result is given with a precision of 0.1 km/sec. No ecliptical co-ordinates of the star or longitudes of the sun are required.

A simple way of finding the correction to be applied to observed radial velocities of stars for the motion of the earth can be obtained as follows. It avoids the necessity of computing ecliptical co-ordinates of the star as well as the longitude of the sun at the time of observation, thus doing away with the necessity of looking up an ephemeris.

Let α and δ be the equatorial co-ordinates of the star, and let A and D be similar co-ordinates for the point on the ecliptic toward which the earth moves with a velocity V_a at the time of observation. The reduction will be $V_a \times$cosine of the angle between α, δ and A, D or

$$\left.\begin{aligned} V &= V_a \sin D \sin \delta + V_a \cos D \cos(\alpha - A) \cos \delta \\ &= M \sin \delta + N \cos(\alpha - A) \cos \delta \,. \end{aligned}\right\} \quad (1)$$

Here $M = V_a \sin D$ and $N = V_a \cos D$, and they may be considered as functions of the longitude of the sun ($\odot$). But it is simpler to use only one independent variable, namely, A, which can be found from $\odot$ by

$$\tan A = \cos \epsilon \cot(\odot - i) \,, \quad (2)$$

where ϵ is the obliquity of the ecliptic, $23°27'$, and i is a small angle, the numerical value of which is given in Table III of W. W. Campbell's *Stellar Motions*, page 66; the same table gives also V_a as a

function of ⊙ so that we can now compute M and N, D being found from

$$\tan D = \sin A \tan \epsilon \ . \tag{3}$$

Without any loss in accuracy the process is further shortened by using the calendar date instead of the longitude of the sun (⊙); for a time-interval of more than fifty years the longitude of the sun repeats itself with a sufficient approximation on every calendar day of a four-year cycle beginning, for instance, with a leap year. Once for all a table is computed by taking from the ephemeris for four successive years at Greenwich midnight of every day the longitude of the sun and finding A by equation (2). The table has the form:

	Leap Year	Leap Year +1 Year	Leap Year +2 Years	Leap Year +3 Years	Diff.
Jan. 1	12^h34^m3	12^h37^m1	12^h36^m2	12^h35^m2	
2	38.0	40.8	39.9	39.0	3^m7
3	41.8	44.5	43.6	42.7	3.7
4	45.4	48.2	47.3	46.3	3.6
5	12 49.1	12 52.0	12 51.0	12 50.0	3.7

In this way we avoid further use of the nautical almanac.

The numerical values of M and N are next computed by equations (2) and (3) for every half-hour of the argument A. These are not put into tabular form but carried on a diagram on cross-section paper on which all the computation is done by the method of alignment. The functions M and N are represented as curves (Fig. 1), the abscissae being km/sec. and the ordinates the values of the independent variable A from 0 to 24 hours. For any date we find A from the table, and then M and N could be read to 0.1 km/sec. on their respective curves. However, these values themselves are not necessary as we use only the vertical lines corresponding to these abscissae.

The first term, $M \sin \delta$ in (1), is obtained by means of scale I, which represents the values of $\sin \delta$, but is graduated in degrees. The intersection m of a straight line joining I to the origin O with the vertical of M gives in Mm the first term, which is read to 0.1 km/sec. Its sign is found from the M-curve.

Scale II represents $\cos (\alpha - A)$, the argument being written in time. The straight line connecting II with the origin O intersects

the vertical of N in n, so that nN represents the product $N \cos(\alpha - A)$. Without reading off this quantity we carry it horizontally along the line $n\ n'\ n''$, which intersects in n' the line OIII connecting the origin O with the division δ on scale III, representing $\cos \delta$; $n'n''$ represents the value of the second term in equation (1), and its sign is given by scale II.

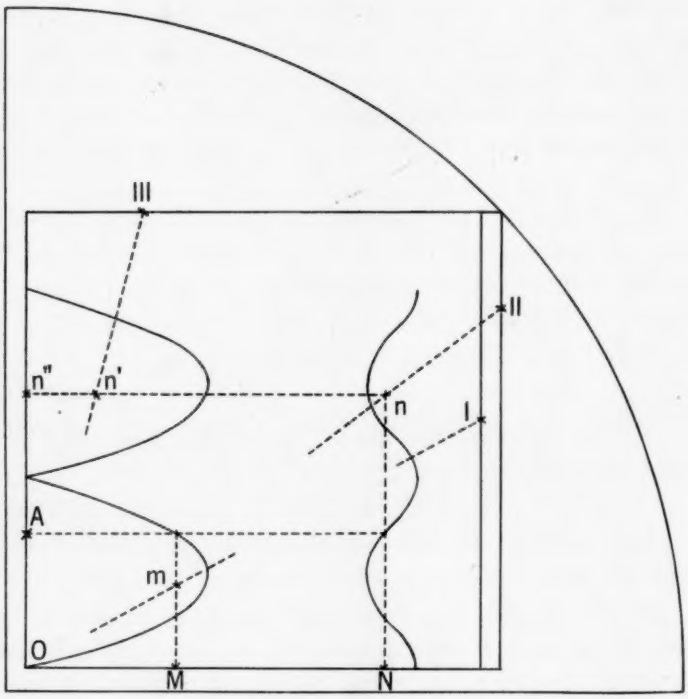


FIG. 1.—Diagram for deriving the reduction to the sun

The lines OI, OII, and OIII are not drawn, but are materialized by threads stretched from the origin O, over the edge of a board cut in the shape of a quadrant with O as a center, and drawn taut by small weights. The cross-section paper used for this purpose is 16×16 inches in size; one km/sec. is represented by $\frac{1}{2}$ inch and is easily read to 0.1 km/sec. In order to keep the paper always flat it is fastened to the board only at the origin O, which is marked by a pin to which the threads are fastened with a loop.

Finally, a remark about precession. In order to maintain the required accuracy of 0.1 km/sec. it is of course necessary that both the star (α, δ) and the direction of the motion of the earth (A, D) be referred to the same equinox. It is much easier to reduce A, D to the standard equinox used for the star than to reduce α, δ to the equinox of the year of observation. The yearly precession of the point A, D can be reduced to a function of A, and could be put in a table of double entry with A and the time-interval as arguments. Since only a small degree of accuracy is required in this computation, it can better be obtained graphically by a special "precession curve" represented on the same cross-section paper. The precession is read on the vertical line passing through the particular value of A, and the ordinate giving that precession is found by reading the value interpolated between the oblique lines corresponding to ten-year intervals. The precession is applied to A, and then the computation is continued with the corrected A. The whole process is very much simpler to use than to explain. Continuous use for over a year has demonstrated its precision and speed. Both in rapidity and in ease of operation it has the advantage over the method proposed by F. Henroteau (*Popular Astronomy*, **33**, 248, 1925) which requires actual drawing on large pieces of tracing cloth.

The writer would be glad to supply a copy of the diagram to anyone who wishes to use it.

Yerkes Observatory
September 1926

SPECTROSCOPIC MAGNITUDES OF A-TYPE STARS

By A. VIBERT DOUGLAS

ABSTRACT

A study of spectra of A-type stars has resulted in seven criteria being found by which absolute magnitudes and hence parallaxes may be determined. These criteria include both *widths* and *relative intensities* of *lines*. *Parallaxes* thus determined, when compared with trigonometric parallaxes and those from moving clusters and spectroscopic parallaxes from Mount Wilson and Arcetri, seem to indicate that a *greater individual accuracy* can be obtained by the use of such criteria than by adopting a statistical mean magnitude for each spectral subdivision.

INTRODUCTION

Absolute magnitudes of A-type stars have been determined spectroscopically at Mount Wilson, Arcetri, Upsala, and Yerkes observatories. Adams and Joy at Mount Wilson[1] and later Abetti at Arcetri[2] relied upon careful classification of the spectra into decimal subdivisions of class A and then the adoption of the statistical mean magnitude associated with each subclass. Lindblad[3] found that a comparison of the density of the regions $\lambda\lambda$ 3884–3907 and $\lambda\lambda$ 3907–3935 gave a correlation with absolute magnitude for stars of classes B8–A3. O. Struve[4] obtained relations between magnitude and the width of λ 4481 throughout the range of A stars.

During the summer of 1925, by the courtesy of the Director of the Yerkes Observatory, the writer was given the opportunity of making a study of the large collection of one-prism slit spectrograms of A stars taken with the Bruce spectrograph attached to the 40-inch refractor. The aim was to find several criteria for the determination of magnitude, and it was hoped that by the application of these a value of magnitude for a given star might be obtained upon which greater reliance might be placed than can be accorded to the average magnitude per spectral subclass.

[1] *Mt. Wilson Contr.*, No. 244; *Astrophysical Journal*, **56**, 242, 1922.

[2] *Pubblicazioni della R. Università degli Studi di Firenze*, No. 42, 1925.

[3] *Nova Acta Regiae Societatis Scientiarum Upsaliensis* (4), **6**, 5, 1925.

[4] Unpublished. See brief statement in *Abstracts of Theses, 1923–24*, "University of Chicago Science Series," **2**, 57, 1926.

CRITERIA

The spectral regions studied by Lindblad are beyond the range of good definition on the Yerkes plates, so that this criterion was inapplicable. The method of taking the relative intensities of certain arc and spark lines, used with such success by many investigators in the case of stars of later type, was an obvious line of attack. In A0 stars the number of absorption lines is very limited, and of these the number of known origin and series relation which are unblended is yet smaller, so that the choice of lines theoretically suitable is not great. The writer was guided less by theory than by appearances in selecting the ratios λ 4215:λ 4227, λ 4233:λ 4227, λ 4535:λ 4481, λ 4549:λ 4481. But the choice was justified, for in each case correlations were found to exist between these ratios and absolute magnitude.[1] The estimates of ratio of intensity were made by eye, a low-power magnifying lens being used. No attempt was made to record a factor indicative of the intensity of individual lines, the ratio of the intensities of the two closely adjacent lines being estimated directly in the case of each of the four pairs.

The second natural line of attack is that of line width. There are strong theoretical grounds, chiefly involving Rayleigh scattering, that lead one to anticipate relations between line width and absolute magnitude. The writer has found such correlations in the case of λ 4481, $H\delta$, and the K line of calcium.[2] There are intangible factors, such as Doppler effects arising from stellar rotation or from atomic agitation, which might conceivably play an important rôle in disturbing any general relation. It seems unlikely that the ambiguity involved in the writer's relations is due to these causes since exactly similar ambiguities are present in the correlations with intensity ratios. Reference will be made to this again.

The material upon which the criteria are based consists of spectrograms of thirty-one stars of the Ursa Major and Taurus clusters for which reliable parallaxes have been determined by Rasmusson,[3] and also of forty-nine stars having known trigonometric parallaxes. Relative to these eighty stars the systematic error of the absolute magnitudes determined from the writer's seven criteria is

[1] *Journal of the Royal Astronomical Society of Canada*, **20**, 8, 1926. [2] *Ibid.*

[3] *Meddelanden från Lunds Astronomiska Observatorium*, Serie II, No. 26, 1921.

found to be −0.04 mag. and the probable error of an individual magnitude, ±0.5 mag.

The spectra were all classified, as is done at Mount Wilson, according to the sharpness (*s*) or nebulosity (*n*) of the absorption lines and, provisionally, separate solutions were made for each group with respect to each of the seven criteria. In the case of $H\delta$, a strong correlation was found between its width and magnitude for the *s* group, but no correlation whatever was apparent in the case of the *n* group. For the other criteria both *n* and *s* groups yielded correlations. The ambiguity above referred to arises from the fact that not one of the criteria is single valued, the plotted data in each case falling into two or more groups, each of which could be fairly well represented by a linear solution. That this is the case both for the widths of absorption lines and for the ratios of intensities of pairs of lines points to some general complexity in the atmospheres of stars of class A.

MAGNITUDES AND PARALLAXES

By the application of the criteria above mentioned the absolute magnitudes and parallaxes of two hundred stars of classification B9–F0 have been determined from an investigation of the Yerkes spectrograms. These results are given in Table I, where for comparison, the corresponding values obtained by trigonometric, group motion, or Mount Wilson spectroscopic methods are also given. This number includes seventy-three of the eighty for which trigonometric or group parallaxes are known, and the probable error of ±0.5 mag. relative to these compares favorably with the probable error of ±0.4 mag. of the spectroscopic magnitudes of stars of later type as determined at Mount Wilson.

Among the two hundred stars are one hundred and eight whose absolute magnitudes have been determined at Mount Wilson. Comparison indicates that the writer's magnitudes are systematically less by 0.09 with a probable error of one difference of ±0.3. Another twenty-two stars not included above are found in the Arcetri list, and relative to these the writer's magnitudes show similar agreement—systematic error, −0.03; probable error, ±0.3.

In comparing the mean magnitude per spectral subclass, it should be remarked that the writer has not adopted the Henry

TABLE I

SPECTROSCOPIC MAGNITUDES AND PARALLAXES OF 200 A STARS

Boss	Name	H.D. m	Trig. or Gr.		Mt. Wilson			Douglas		
			M	p	Class	M	p	Class	M	p
10	α And	2.2			A1n	1.1	0″.060	A1n	1.0	0″.059
43	θ And	4.4			A1n	1.5	.026	A3n	1.7	.029
50	σ And	4.5	0.6	0″.017T	A0n	1.1	.021	A0n	0.2	.014
145	π Cas	5.0						A1n	1.3	.018
154	+54°143	5.5			A2s	1.1	.014	A1s	0.9	.012
203	μ And	3.9	1.5	.033T				A6n	2.0	.042
246	41 And	5.2						A4n	2.2	.025
269	82 Psc	4.9						A4n	1.6	.022
295	89 Psc	5.3			A1n	1.5	.018	A2n	1.4	.017
300	υ Psc	4.7	0.9	.017T				A2n	2.3	.033
314	δ Cas	2.8			A3n	2.0	.068	A5n	2.5	.087
368	+42°345	5.5						A5n	2.5	.025
370	ω Cas	5.5						A2s	0.9	.012
422	γ Ari N	4.8						A0n	0.7	.015
423	γ Ari S	4.8						A2s	0.6	.014
428	β Ari	2.7	1.9	.068T				A5s	1.9	.069
441	λ Ari	4.8	2.1	.029T				A7n	2.1	.029
446	48 Cas	4.7	1.2	.020T	A4s	2.0	.029	A3n	2.0	.029
449	50 Cas	4.1			A1n	1.1	.025	A1s	1.2	.026
452	47 Cas	5.4						A1n	1.4	.016
463	α Psc Ft	5.2			A3n	1.8	.022	A3s	1.5	.018
463	α Psc Br	4.3						A3s	0.4	.017
466	ε Tri	5.4			A2n	1.5	.016	A1n	2.3	.024
476	κ Ari	5.1						A5s	1.9	.023
480	58 And	4.8						A1n	1.8	.025
482	β Tri	3.1	−0.7	.017T				A3s	1.3	.044
522	62 And	5.1			A1n	0.9	.014	A0n	0.3	.011
550	ι Cas	4.6			A3s	1.4	.021	A3s	2.0	.030
560	ξ Cet	4.3						A0n	0.8	.020
597	ν Ari	5.8						A2n	1.6	.014
606	33 Ari	5.4	−4.6	.001T				A1n	0.5	.010
628	38 Ari	5.2						A6s	2.4	.028
629	μ Cet	4.4	2.2	.036T				A7n	1.9	.032
666	−4°502	5.3			A0n	1.1	.014	A0n	1.2	.015
674	ε Ari Br	5.3	1.6	.018T	A3s	1.0	.014	A2s	1.2	.015
677	−3°470	5.2						A2n	1.1	.015
730	ζ Ari	5.0						A1n	0.9	.015
791	+54°684	5.0			A0n	0.9	.015	A0n	1.1	.016
850	+70°257	5.4						A4s	1.1	.014
883	+25°624	5.4						A3n	2.5	.026
923	τ^9 Eri	5.1						A1s	0.5	.012
932	ν Tau	3.9						A4s	1.0	.026
971	46 Tau	5.4						A8s	2.5	.026
974	+53°750	5.1			A1n	1.1	.015	A0n	1.2	.017
986	b Per	4.6						A0s	0.6	.016
998	56 Tau	5.3						A1s	0.3	.010
1007	58 Tau	5.3	2.4	.027G	A9n	2.8	.031	A6n	2.0	.022
1022	64 Tau	4.8	2.1	.029G	A6n	2.4	.034	A5s	2.0	.028
1023	66 Tau	5.1			A3n	2.0	.017	A2n	2.1	.025
1026	κ^1 Tau	4.4	1.3	.025G	A3s	1.8	.030	A2n	1.5	.026
1027	κ^2 Tau	5.4	2.8	0.030G	A3n	2.1	0.022	A1n	1.7	0.018

TABLE I—*Continued*

Boss	Name	H.D. m	Trig. or Gr.		Mt. Wilson			Douglas		
			M	p	Class	M	p	Class	M	p
1029	68 Tau	4.2	1.3	0".026G	A3s	1.4	0".028	A3s	1.7	0".032
1033	υ Tau	4.4	1.6	.028G	A2n	1.8	.030	A2n	......	......
1034	71 Tau	4.6	1.8	.028G	A0n	1.3	.022	A2n	......	......
1046	θ^2 Tau	3.6	0.7	.026G	A3s	1.6	.042	A5s	1.7	.042
1047	79 Tau	5.1	2.3	.028G	A2n	2.0	.024	A4n	2.1	.025
1051	80 Tau	5.7	2.8	.026G	A3n	2.1	.019	A3n	2.6	.024
1054	+15°637	4.8	2.1	.029G	A5s	2.0	.028	A5s	2.1	.029
1067	ρ Tau	4.8	1.9	.027G	A2n	2.0	.028	A2n	1.2	.019
1087	90 Tau	4.3	1.6	.028G	A3n	2.1	.036	A3n	1.8	.032
1088	51 Eri	5.3	......	......	A4s	2.0	.022	A6s	2.3	.025
1090	σ^2 Tau	4.9	1.6	.023G	A3n	2.2	.028	A3n	2.2	.029
1092	+7°681	5.6	2.3	.023G	A5s	2.2	.020	A5s	2.5	.024
1095	−12°955	5.0	......	......	A4s	1.7	.022	A3s	1.8	.023
1114	+10°621	5.4	2.6	.029G	A8s	2.6	.027	A5n	2.1	.022
1117	4 Cam	5.4	1.4	.016T	......	......	......	A7s	1.9	.020
1122	+11°646	5.4	1.9	.020G	A7s	2.2	.024	A6s	1.8	.019
1143	97 Tau	5.1	2.2	.026G	A2n	1.7	.021	A1n	1.7	.021
1153	ω Eri	4.5	......	......	......	......	......	A0n	1.9	.030
1194	ι Tau	4.7	1.6	.024G	A3n	2.1	.030	A4n	1.4	.022
1220	β Eri	2.9	0.5	.033G	A1n	1.5	.052	A0n	1.6	.055
1244	14 Aur	5.1	......	......	......	......	......	A7s	2.6	.032
1268	19 Aur	5.2	......	......	......	......	......	A6s	2.3	.026
1352	38 Ori	5.3	......	......	......	......	......	A0n	1.3	.016
1392	49 Ori	4.9	......	......	......	......	......	A0n	0.9	.016
1452	31 Cam	5.3	......	......	......	......	......	A1s	0.7	.012
1453	ξ Aur	4.9	......	......	A2s	1.4	.020	A1s	0.6	.014
1482	θ Aur	2.7	−0.9	.019T	A1s	0.6	.037	A1s	0.1	.030
1488	60 Ori	5.3	......	......	......	......	......	A0n	0.1	.009
1492	2 Mon	5.1	......	......	......	......	......	A7s	1.8	.022
1516	17 Lep	5.0	......	......	......	......	......	A6s	3.2	.044
1575	2 Lyn	4.4	1.5	.026T	A2s	1.2	.024	A1n	0.7	.018
1690	γ Gem	1.9	0.5	.053T	A2s	0.9	.063	A2s	0.3	.048
1714	26 Gem	5.1	......	......	......	......	......	A1n	1.4	.018
1716	12 Lyn	4.9	......	......	A1n	1.1	.014	A1n	1.1	.017
1759	36 Gem	5.2	......	......	......	......	......	A0s	0.4	.011
1763	θ Gem	3.6	0.4	.023T	......	......	......	A0n	0.5	.024
1782	−0°1487	5.3	......	......	......	......	......	A4n	1.7	.019
1853	22 Mon	4.1	......	......	......	......	......	A0n	0.5	.019
1886	λ Gem	3.6	1.5	.038T	A2n	1.5	.038	A2n	1.8	.044
1928	21 Lyn	4.5	......	......	......	......	......	A1s	0.7	.017
1968	−22°1897	4.8	......	......	......	......	......	A8s	2.0	.028
1974	δ^1 C Mi	5.3	......	......	......	......	......	A5n	2.3	.025
2051	4 Car	5.1	......	......	A7n	2.6	.031	A5n	2.0	.024
2078	φ Gem	5.0	......	......	A0n	1.1	.016	A1n	1.1	.017
2088	+79°265	5.3	......	......	......	......	......	A0s	0.7	.012
2091	85 Gem	5.4	......	......	......	......	......	A1s	1.0	.013
2120	−18°2118	4.6	......	......	......	......	......	A0n	0.7	.017
2138	8 Cnc	5.1	......	......	......	......	......	A0n	0.6	.013
2185	29 Lyn	5.5	......	......	A3n	2.0	.019	A3n	1.9	.019
2237	30 Mon	4.0	−0.6	.012T	A0n	0.9	0.024	A0n	0.1	.017
2264	2 U Ma	5.4	......	......	......	......	......	A6s	2.2	.023
2327	γ Cnc	4.7	−0.3	0.010T	......	......	......	A1n	0.4	0.014

TABLE I—*Continued*

Boss	Name	H.D. m	Trig. or Gr.		Mt. Wilson			Douglas		
			M	p	Class	M	p	Class	M	p
2339	49 Cnc	5.6	......	......	......	......	......	A5s	1.2	0".013
2398	59 Cnc	5.5	......	......	......	......	......	A2n	2.0	.020
2404	ι U Ma	3.1	2.9	0".090T	A4n	2.2	0".066	A4n	1.9	.058
2407	α Cnc	4.3	......	......	A4s	1.7	.030	A4s	1.8	.032
2479	θ Hyd	3.8	−0.1	.017T	A1n	1.3	.032	A0n	......	......
2495	38 Lyn	4.0	1.8	.037T	B9n	0.6	.021	A0n	1.9	.038
2559	τ² Hyd	4.5	......	......	......	......	......	A3n	1.9	.030
2584	42 Lyn	5.2	......	......	A5n	2.4	.026	A5n	2.1	.024
2637	φ U Ma	4.5	......	......	A1s	0.9	.015	A2s	1.2	.022
2642	22 Leo	5.3	3.2	.039T	A5n	2.2	.024	A4n	2.3	.025
2655	31 U Ma	5.3	......	......	......	......	......	A1n	0.0	.009
2692	21 L Mi	4.5	......	......	A2n	1.8	.028	A2n	1.3	.023
2697	15 Sex	4.5	......	......	......	......	......	A0s	0.0	.013
2729	λ U Ma	3.5	......	......	......	......	......	A4s	1.2	.035
2735	ε Sex	5.4	......	......	......	......	......	A7s	2.6	.028
2754	30 U Ma	4.9	......	......	......	......	......	A3s	1.1	.017
2900	ω U Ma	4.8	......	......	......	......	......	A0s	0.0	.011
2930	β U Ma	2.4	0.8	.046G	A3s	1.0	.054	A3s	0.3	.038
2932	60 Leo	4.4	0.1	.014T	......	......	......	A4s	0.2	.014
2972	δ Leo	2.6	2.2	.085G	A2n	1.7	.066	A1n	1.0	.048
2974	θ Leo	3.4	0.0	.021T	A2s	0.9	.032	A3s	0.2	.023
2987	55 U Ma	4.8	......	......	A0n	0.7	.016	A1s	0.2	.012
2990	σ Leo	4.1	......	......	B9s	−0.2	.014	B9s	0.0	.015
3023	57 U Ma	5.3	......	......	B9n	0.8	.012	B9n	0.4	.010
3063	59 U Ma	5.5	......	......	A4n	2.0	.020	A6n	1.9	.019
3088	ξ Vir	5.1	......	......	A1n	1.5	.019	A1n	1.2	.017
3097	4 Vir	5.2	......	......	A1n	0.8	.015	A1s	0.6	.012
3101	β Leo	2.2	2.5	.114T	A2n	1.7	.079	A5s	2.4	.110
3117	γ U Ma	2.5	0.6	.041G	A0n	0.9	.048	A0n	0.7	.044
3126	η Crt	5.2	......	......	......	......	......	A0s	0.7	.013
3139	π Vir	4.6	......	......	......	......	......	A3n	1.4	.023
3182	+78°412	5.1	......	......	......	......	......	F0n	2.9	.036
3190	δ U Ma	3.4	1.7	.045G	A0n	0.9	.032	A0n	......	......
3210	η Vir	4.0	......	......	......	......	......	A2s	1.2	.028
3240	14 Com	5.2	......	......	......	......	......	A6n	3.0	.036
3244	16 Com	5.0	......	......	......	......	......	A4s	2.6	.033
3266	21 Com	5.4	......	......	A3s	1.0	.014	A3s	1.0	.013
3277	21 Vir	5.4	......	......	B9n	0.6	.010	B9n	0.2	.009
3283	23 Com	4.8	......	......	......	......	......	A0s	0.3	.013
3309	ρ Vir	5.0	......	......	B9n	0.6	.014	B9n	0.4	.012
3310	31 Vir	5.5	......	......	B9n	0.6	.010	A0n	0.7	.011
3323	32 Vir	5.2	......	......	A6n	2.4	.027	A7s	2.4	.028
3354	+84°289	5.8	......	......	......	......	......	A0s	0.4	.008
3356	+84°290	5.3	......	......	......	......	......	A0n	0.2	.009
3370	α¹ C Vn	5.4	......	......	......	......	......	A8s	3.3	.028
3371	α² C Vn	2.9	1.1	.044T	A1s	0.6	.034	A1s	1.1	.044
3409	θ Vir	4.4	−0.4	.011T	A2s	0.9	.020	A2s	−0.3	.011
3450	21 C Vn	5.1	......	......	......	......	......	B9n	0.3	.011
3474	ζ U Ma	2.4	0.6	.044G	A2s	1.1	.054	A2s	0.6	.044
3475	ζ² U Ma	4.0	2.3	.046G	A8s	2.0	.052	A5s	1.8	.036
3480	80 U Ma	4.0	2.1	.042G	A1n	1.1	.026	A1n	2.2	.044
3506	ο Vir	4.9	0.6	0.014G	A3s	1.5	0.021	A5s	0.7	0.014

TABLE I—*Continued*

Boss	Name	H.D. m	Trig. or Gr.		Mt. Wilson			Douglas		
			M	p	Class	M	p	Class	M	p
3508	ζ Vir	3.4	......	......	......	......	......	A0n	0.9	0″.032
3509	81 U Ma	5.5	......	......	......	......	......	A0n	0.8	.011
3512	24 C Vn	4.6	......	......	......	......	......	A0n	0.7	.017
3518	25 C Vn	4.9	3.5	0″.052T	A1n	1.5	0″.021	A1n	1.8	.024
3526	+11°2589	5.5	1.4	.015T	A7n	2.5	.018	A7n	2.5	.025
3530	82 U Ma	5.3	......	......	......	......	......	A1n	1.0	.014
3561	84 U Ma	5.5	......	......	......	......	......	A1s	0.6	.010
3612	τ Vir	4.3	......	......	A1n	1.1	.023	A0n	1.4	.026
3654	κ Boo	4.6	1.6	.025T	A4n	2.2	.034	A5n	1.8	.028
3666	λ Boo	4.3	2.4	.041T	A1n	1.1	.023	A0n	1.3	.025
3692	+9°2882	5.1	1.2	.017T	B9n	0.8	.014	B9n	0.9	.014
3722	γ Boo	3.0	......	......	A3n	2.0	.062	A5n	2.3	.072
3749	π Boo Br	4.9	......	......	......	......	......	A2s	−0.3	.009
3752	ζ Boo	4.4	0.4	.016G	A0n	0.9	.020	A0n	0.5	.017
3787	α^2 Lib	2.9	......	......	F1n	2.9	.100	A6n	2.2	.072
3911	+52°1869	5.5	......	......	A2n	1.5	.016	A2n	1.8	.018
3928	γ U Mi	3.1	......	......	......	......	......	A2s	1.5	.048
3939	10 Ser	5.1	......	......	......	......	......	A6s	2.5	.030
3960	δ Ser Br	4.2	−0.2	.013T	A4n	2.4	.044	A7n	2.7	.050
3961	α Cr B	2.3	0.3	.041G	A0n	0.9	.052	A1n	0.8	.050
3998	γ Cr B	3.9	0.5	.021T	A0n	1.1	.026	A0n	0.8	.024
4004	+52°1898	5.5	......	......	......	......	......	A1s	0.5	.010
4009	β Ser	3.7	0.6	.023G	A1n	1.1	.030	A0n	0.0	.018
4016	μ Ser	3.6	......	......	A0s	0.4	.022	A0s	1.0	.030
4022	β 946	5.8	......	......	A6s	2.3	.020	A8s	1.9	.017
4026	ϵ Ser	3.8	1.5	.035T	A6s	1.8	.042	A4s	1.7	.038
4028	36 Ser	5.2	......	......	A0n	0.9	.014	A0n	1.1	.015
4072	+55°1793	5.0	......	......	A5n	2.5	.032	A4n	1.8	.023
4081	π Ser	4.8	......	......	......	......	......	A3n	1.5	.022
4229	16 Dra	5.6	......	......	B9s	0.4	.009	B9s	0.4	.009
4232	17 Dra	5.6	......	......	......	......	......	B9n	0.2	.008
4376	δ Her	3.2	0.4	.028T	A0n	0.9	.035	A0n	1.0	.036
4581	72 Oph	3.7	1.5	.037T	A5s	1.8	.042	A5s	2.1	.048
4747	ϵ^1 Lyr	5.1	......	......	......	......	......	A1n	1.1	.016
4749	ϵ^2 Lyr	5.1	......	......	......	......	......	A1n	1.3	.017
4752	ζ^1 Lyr	4.3	1.4	.026T	A5s	2.2	.037	A4s	1.5	.028
4754	ζ^2 Lyr	5.9	3.3	.030T	A1n	1.5	.013	A1n	1.9	.016
4761	111 Her	4.4	3.1	.056T	A2n	2.0	.034	A4n	2.6	.044
4802	θ^1 Ser	4.5	......	......	......	......	......	A1n	1.3	.023
4803	θ^2 Ser	5.4	......	......	......	......	......	A1n	1.8	.019
4824	γ Lyr	3.3	−1.3	.012T	B9s	−0.2	.020	B9n	−0.2	.020
4858	ζ Aql	3.0	0.8	.037T	B9n	0.8	.036	B9n	......	......
4988	ι Cyg	3.9	0.2	.018T	A1n	1.1	.028	A1n	1.0	.026
5048	δ Cyg	3.0	1.7	.055T	A1n	1.1	.042	B9n	......	......
5062	α Aql	0.9	2.5	.203T	A2n	1.7	.145	A1n	2.0	.166
5186	o^1 Cyg	5.0	......	......	......	......	......	A1n	1.6	.021
5187	o^2 Cyg	4.0	......	......	......	......	......	B9s	0.6	.021
5337	ϵ Aqr	3.8	0.6	.023T	A1n	1.6	.037	A1s	1.0	.028
5480	α Cep	2.6	2.2	.084T	A2n	1.3	.056	A2n	2.5	.096
5600	δ Cap	3.0	3.3	.115T	A3n	2.2	.068	A6s	2.2	.069
6031	κ Psc	4.9	3.1	0.043T	A3s	1.2	0.018	A3s	0.7	0.014

Draper classification but a personal classification following very closely that of Mount Wilson investigators. Hence it is satisfactory to find that the writer's average magnitudes both for *n* and *s* stars of each subclass show a very close agreement with the means adopted by Mount Wilson and by Arcetri.

A crucial test of the individual accuracy of certain magnitudes is that suggested by Shajn,[1] based upon the fact that the components of a binary system have the same parallax and should therefore have the same difference in their absolute magnitudes as in their apparent magnitudes. In other words, for each pair the following relation should hold:

$$\Delta M - \Delta m = 0 \ .$$

For twelve such pairs the values of absolute magnitude determined by means of the writer's criteria gave an average of

$$\Delta M - \Delta m = \pm 0.34 \ .$$

As this is within the probable error of individual values of M, the conclusion is that this test gives evidence in favor of the accuracy of this method of determining spectroscopic magnitudes.

One pair calls for special mention—Boss 4752, 4754 (ζ^1 and ζ^2 Lyrae). The trigonometric values of absolute magnitude are in good accord, but the spectroscopic magnitudes as determined at Mount Wilson lead to

$$\Delta M - \Delta m = -2.3 \ ,$$

while the writer's values lead also to a large discrepancy, -1.2. The type of the fainter component (A1*n*) is certainly earlier than that of the primary (A4*s*),[2] and its magnitude must therefore be very much greater than the average magnitude (1.3) for stars of class A1*n*. This represents a case where the method of mean magnitude per spectral subclass fails utterly. The present criteria are not completely successful, but they improve matters to some extent and at least give ΔM and Δm the same sign.

[1] *Astrophysical Journal*, **62**, 104, 1925.

[2] H.D. classification for ζ^1, ζ^2 Lyrvae, A3, A3; Mount Wilson classification, A5*s*, A1*n*.

The natural expectation that any set of absolute magnitudes would show a correlation with the corresponding proper motions was confirmed by Mount Wilson investigators with regard to their spectroscopic magnitudes and by Dr. Struve with respect to the writer's magnitudes. But an attempt to find an analogous relation using reduced proper motion indicates that no such relation exists, the correlation coefficient evaluated rigorously for H and M in respect to one hundred and twenty-nine stars being 0.030. The applicability of the H function in this case evidently requires further investigation.

OUTSTANDING PROBLEMS

That the spectra of A stars present a peculiar problem has been stressed by Dr. Shapley[1] and others.[2] This investigation is a confirmation of the belief that there is present in the atmospheres of stars, at this critical stage of evolution, some unknown or at least unrecognized factor which plays a part in determining the nature of the spectra. What is the true significance of the *s* or *n* character of the lines in different spectra? Why are intense strontium and silicon lines so frequently associated with a spectrum having sharp lines? What factors are just balancing or merging their effects when a spectrum is neither distinctly *s* nor *n* but of so intermediate a character that two investigators will differ as to the group to which it belongs, while a third investigator meets the difficulty by calling it *sn?*

Perhaps a thorough study of the variations in the widths of lines associated with other spectral characteristics may lead eventually to the understanding of some of these problems.

A paper containing a more complete discussion of the results obtained for the individual stars studied, and the curves used in establishing the criteria, is published in the *Journal of the Royal Astronomical Society of Canada*, for October 1926, covering pages 265 to 302 of Volume **20** of that *Journal.*

McGill University, Montreal
October 1926

[1] "Report of the Committee on Spectral Classification," *Transactions of the International Astronomical Union*, **2**, 117, 1925.

[2] *Harvard Circular*, No. 264.

MINOR CONTRIBUTIONS AND NOTES

THE DISTRIBUTION OF ENERGY OVER THE SUN'S DISK

Moll, Burger, and van der Bilt[1] criticize the accuracy and completeness of the Smithsonian experiments on the distribution of energy over the sun's disk. As numerous investigators in several countries have made extensive use of these observations for solar and stellar investigations, it may be of interest to readers of the *Astrophysical Journal* to state that the criticisms of the Dutch authors are quantitatively considered in my very recent paper entitled "The Distribution of Energy over the Sun's Disk" (*Smithsonian Miscellaneous Collections*, **78**, No. 5, 1926). It is shown there that while errors in these Smithsonian absolute values exist, which are of the sign claimed by the Dutch authors, these errors appear not to exceed 0.3 per cent at either 95 or 92 per cent out along the solar radius. We did not carry the work into the difficult region still nearer the sun's limb because it was not useful for our purpose, namely, the study of solar variation.

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Smithsonian Astrophysical Observatory
Washington, D.C.
September 20, 1926

[1] *Bulletin of the Astronomical Institutes of the Netherlands*, **3**, 83, 1925. See also the "Council Report" of the Royal Astronomical Society for the year 1925 (*Monthly Notices*, **86**, 229, 1926).

REVIEWS

Le Magnetisme. By P. WEISS and G. FOEX. Paris: Librairie Armand Colin, 1926. 16mo. Pp. viii+215. Fr. 7.

This is a very thorough and complete work on magnetism. The style is readable, and the authors have taken pains to present their subject matter in careful and minute detail.

The first chapter is a general introduction: it is a review of the definitions and fundamental ideas underlying the work. The conceptions of uniform, continuous, noncontinuous, and molecular fields are introduced, and the equations for the field-strengths of various coils and circuits are presented.

Chapter ii treats of the phenomena of diamagnetism. It contains a full discussion of the laws of Curie, and examples of experimental work verifying these laws are given. The chemical phases of diamagnetism are taken up and studied fully.

The next two chapters are occupied with paramagnetism, and the thermodynamic basis of Curie's laws is presented. This section contains a full account of the work of Boltzmann and Langevin on perfect and real gases, dilute and concentrated solutions, and crystals; and experimental results are cited. Onnes's work on cryomagnetism is mentioned.

Five chapters are given to ferromagnetism. Curves of hysteresis, susceptibility, etc., are treated fully, and much space is given to the effect of temperature on magnetic strength. Spontaneous magnetism is mentioned. There is a detailed study of the magnetization curves in strong and weak fields with temperature variations for iron and nickel, and the ferromagnetism of crystals is treated at length. The heat of magnetization is calculated from the laws of thermodynamics.

The rest of the book contains various hypotheses and theories of the magnetic field. Calculated and observed values of atomic moments are given, and the relation of atomic moment to the periodic system is explained. The last subject discussed is the work of Gerlach and Stern on magnetism and the quantum theory.

The book contains a very complete bibliography as an Appendix.

The diagrams are poor and there are places where cuts would make the work clearer, but, taken as a whole, the book is pleasing and is a very valuable addition to the literature of the subject.

B. A. WOOTEN